Inheritance of Genetic Traits and Breeding Methodologies Based on Various Segregating Generations in Blackgram [*Vigna mungo* (L.) Hepper]

BY

MUHAMMAD ARSHAD

Department of Biological Sciences
Quaid-i-Azam University
Islamabad, Pakistan

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بسم الله الرحمن الرحيم

Inheritance of Genetic Traits and Breeding Methodologies Based on Various Segregating Generations in Blackgram [*Vigna mungo* (L.) Hepper]

By

Muhammad Arshad

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In the name of

Allah,

the Compassionate,

the Merciful

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"It is Who sends down water from the skies and brings out of it every thing that grows, the green foliage, the grain lying close, the date Palm trees with clusters of dates and the gardens and olives and pomegranates, so similar yet so unlike".

(Al-Quran, Sura Al-Aanan. 99)

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DECLARATION

This is to certify that this dissertation entitled, "Inheritance of genetic traits and breeding methodologies based on various segregating generations in blackgram [*Vigna mungo* (L.) Hepper]" submitted by MUHAMMAD ARSHAD is accepted in its present form by the Department of Biological Sciences, Quaid-i-Azam University, Islamabad, Pakistan as satisfying the dissertation requirements for the degree of Ph. D. in Biological Sciences.

Chairperson ____________ 4.12.2004

Supervisor ____________

Co-supervisor ____________

External Examiners 1) ____________
Dr. M. H. Soomro

External Examiners 2) ____________
Dr. Akhlaq Hussain

Dated: December 4, 2004.

Dedicated

To

My Family, Parents, Brother & Teachers

ABSTRACT

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The present study was conducted to evaluate three breeding methods i.e. Bulk Method, Single Seed Descent and Single Plant Progenies in F_4 generation of blackgram to identify the most appropriate one for particular hybrid or character at two locations. In addition, inheritance of qualitative traits and hybrid performance for four generations was also studied. Inheritance study comprised four plant traits (pubescence, pod colour, seed coat colour and presence of spots on seed coat) in three crosses. Breeding methods in eleven crosses were investigated for plant height, number of branches plant^{-1}, pods plant^{-1}, length pod^{-5}, seed pod^{-5}, 100 seed weight plant^{-1}, biological yield plant^{-1}, grain yield plant^{-1} and harvest index over four generation at National Agricultural Research Center, (research station) and Fateh Jang (farmer's field).

Eleven crosses were selected in F_2 from a six parent diallel and seeds were divided into three groups to evaluate Bulk Method, Single Seed Descent and Single Plant Progeny method. Two crosses (Mash 1/9020 and 9020/9012) gave better response to Bulk Method at both the locations, while 9020/Mash 1 performed better for this method at NARC location only. All the crosses except 9025/Mash 1 and 9025/9026 showed their worth in single seed descent. In single plant progenies at FJ, all the crosses showed better performance except 9020/9012.

Plant height, pods plant^{-1}, pod length, seed pods^{-1}, 100 seed weight, biological yield plant^{-1} and grain yield plant^{-1} showed better performance in single plant progenies at FJ while single seed descent showed its worth for number of branches, pods plant^{-1}, pod length, pod seed, biological yield plant^{-1}, grain yield plant^{-1} and harvest index at NARC location. Single plant progenies showed the best performance at FJ and it differed significantly for single seed descent at NARC. Bulk method revealed almost similar results at both the location with lowest index score.

Four parents (Mash 1, Mash 3, MM 33-40, and 45726) were used to study inheritance of four qualitative characters, i.e., pubescence, seed coat colour, presence of spots on the seed coat and pod colour. All the four qualitative traits revealed monogenic

nature of inheritance segregating in Mendelian ratio (3:1). The hairiness pattern was observed dominant over non-hairiness; brown seed coat colour dominant over green seed coat colour. Presence of spots on seed coat was dominant to absence of spots and black pod colour was dominant over brown pods in blackgram. Out of three hybrids, two (Mash 1/MM33-40 and 45726/MM33-40) revealed linkage between pod colour vs presence of spots on seed coat and pod colour vs seed coat colour that is suggested to be used for preliminary mapping in blackgram.

The data were analyzed for hybrid vigour over the generations and it was observed that the source of variation attributed to hybrids as well as generations representing high proportions of the total sum of squares. A clear response for grouping of F_1 and F_2 was observed, whereas other two generations (F_3 and F_4) were intermixed, although a low level of separation was observed. On the basis of performance and hybrid vigour, three hybrids (Mash 3/Mash 1, 9012/ 9025 and 9020/Mash 1) exhibited better potential. The hybrids with high mean performance and hybrids vigour are expected to give better chance for selection to develop superior cultivars of blackgram.

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GLOSSARY OF TERMS AND ABBREVIATIONS

100 SW	100 seed weight per plant
5 PL	5 pods length per plant
5 PS	5 pods seeds per plant
AVRDC	Asian Vegetable Research & Development Center, Taiwan
BB, Bb, bb	Allelic notion for pod colour
BM	Bulk method
BP	Better parent
Br	Branches per plant
Br. M	Breeding method
BY	Biological yield per plant
CC, Cc, cc	Allelic notion for seed coat colour
F_1	First filial generation
FJ	Fateh Jang
Gene	The basic unit of inheritance, chemically a DNA sequence which codes for the production of a specific protein molecule.
Genotype	The sum-total of the genes affecting the expression of a character; also employ for a variety or cultivar
g	Gram
GY	Grain yield per plant
h^2	Heritability
HH, Hh, hh	allelic notion for plant hairiness
HI	Harvest index per plant
Hybrid	first generation progeny (F_1) from a cross produced through controlling pollination between two parents
Masl	meter above sea level
monogenic	controlled qualitatively by one or few genes
MP	Mid parent
multigeneic	controlled by many genes
MYMV	Mungbean Yellow Mosaic Virus
NARC	National Agricultural Research Center, Islamabad, Pakistan
PGRI	Plant Genetic Resources Institute
PH	Plant Height per plant
phenotype	a sum-total of the expression of a character
PM	Pedigree method
Pods	Pods per plant
Progeny	the generation obtained after crossing two or more parents
RB	Random bulk
RS	Recurrent selection
SD	standard deviation
SE	standard error
SOV	source of variation
SPP	Single plant progenies
SS, Ss, ss	allelic notion for seed spots
SSD	Single seed descent
TP	Top parent

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MUHAMMAD ARSHAD

INTRODUCTION

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Pulses (grain legumes) are one of the most important dietary constituents worldwide, even though their overall production lags far behind that of the cereals. Yield per unit area is generally less than one-half those of the major cereal grains (Muehlbauer *et al.*, 1998). These are an excellent and inexpensive source of plant protein. When eaten in combination with wheat, rice and other cereals they provide a balanced diet to millions of people. Pulses are known as the 'poor man's meat' in the developing world, while in the developed world they are perceived as 'health food'. According to Hakeem Mian Aziz Ahmad Jhandair (2002) that *Kali dall*, i.e., blackgram (*Vigna mungo*) is used in almost all memory retaining/enhancing medicines, and it is an excellent alternative source of meat. In combination with other pulses especially with chickpea *dall* it becomes the source of Calcium and Phosphorus with excellent taste. Being leguminous, they maintain soil fertility by converting and fixing atmospheric nitrogen in available form through symbiosis with *rhizobial* strains. Malik (1994) stated that rainfed (*barani*) farming system is dominated by food legumes (pulses) and coarse grain. Rural population of rainfed farming system consisted mainly of subsistence growers whose per capita income is considerably below the national average. According to Rao and Subramanian (1970) urdbean (blackgram) and mungbean are relatively better balanced in their amino acid composition than bengal gram, arhar and lentil.

The genus *Vigna* is a tropical plant and comprises about 150 species, most of which are found in Africa and Asia (Faris, 1965; Verdcourt, 1970). Seven species of this genus are cultivated as pulse crops mostly in Asia, Africa and some parts of Latin America (Anishetty & Moss, 1987). It is generally considered that two of these seven cultivated species are of African origin (subgenus *Vigna*) and five are Asiatic origin (subgenus *Ceratotropis*). The Asiatic group consists of mungbean/greengram (*Vigna radiate* L. Wilczek), blackgram/mash/rudbean (*Vigna mungo* L. Hepper), mothbean (*Vigna aconitifolia* Jack. Marechal), azuki bean (*Vigna anhularis* Willd, Ohwi & Ohashi) and ricebean (*Vigna umbellate* Thunb, Ohwi & Ohashi). Mungbean and blackgram have been major pulses in Asia since ancient times (Paroda & Thomas, 1987). At present, mungbean cultivation spreads worldwide because it is easily digested than blackgram (Smartt, 1990 and Ghafoor, 1999). Subcontinent has been considered to be the region with greatest genetic diversity in mungbean and blackgram (Vavilov, 1926, & 1951; Singh *et al.*, 1974; Zeven & de Wet, 1982). Mungbean world wide spread also occurred due to more attention on international or regional research and development but blackgram lacks it.

According to Jain and Mehra (1978) among *Vigna* species, four, viz. V. *radiata, V. mungo, V. aconitifolia* and *V. umbellate* are believed to have originated in the Indian center of origin and *V. unguiculata* in Africa. They also stated a detailed account of *Vigna* species cultivated in India and this includes evaluation, adaptation and their relationship. It is fairly certain now that both greengram and blackgram have not been authenticated in the wild state. Though some botanists have reported that greengram grows wild in India, such reports appear to be based on spotting a poorly growing form of cultivar. de Candolle (1886) believes that both *V. mungo* and *V. radiate* have originated in India. According to Vavilov (1926) *V. radiate* originated in the Indian center of cultivated plants as well as Central Asiatic center, which include Pakistan, Afghanistan, Tadjikistan, Uzbekistan and western Tien-shan. In case of blackgram, Vavilov considers Indian center as primary and the Central Asiatic as only the secondary.

Unlike cereals, pulses have been grown for centuries under marginal conditions of moisture and soil fertility. Energy requirements are critical for legumes because of their indeterminate growth and progressive flowering and seed-setting habits, compared with the synchronous flowering of cereals (Evans, 1980). In addition, grain legumes are often grown on marginal arid areas where they seldom receive fertilizer, irrigation, or pest control chemicals. Indeed, they are often not planted or given agronomic care like cereal crops which are well established (Summerfield, 1981).

Blackgram {*Vigna mungo* (L.) Hepper} is an important summer pulse crop of many South Asian countries (Ghafoor, 1999). The distribution of blackgram is comparatively restricted to wet tropics and is abundantly grown in India, Pakistan, Sri Lanka, Burma, Bangladesh, Nepal, Thailand and some parts of south-east Asia, parts of Africa and America. In West Indies it is grown mainly as a green manure under the name woollypyrol (Jain and Mehra, 1978). The total area, production and yield of pulse crops in Pakistan during the year 2001-02 was 54.7 (000 ha), 27.4 (000 tons) and 504 (kg ha^{-1}), respectively (Anonymous, 2001-02).

Blackgram {*Vigna mungo* (L.) Hepper} belongs to family Leguminosae, diploid chromosome number 2n=22, haploid n=11, is native to Asia (Vavilov, 1926). As a crop of the tropics and subtropics, it is resistant to high temperatures, so it is often grown as a spring/summer crop. It is sensitive to cloudy weather and cannot tolerate frost. In Pakistan, blackgram has received little attention from researchers despite its high nutritive and economic value. The lack of stable and high yielding cultivars, lack of seed production system of existing improved varieties and basic information about production technology are among the important constraints.

Until 1989, there had been no approved variety of blackgram since independence. Land races like Mash-48 and Mash-80 remained under cultivation in Punjab province, a variety Mash-88 was released during 1989. The research focus on blackgram is the most recent in Pakistan. National Agricultural Research Center (NARC), Islamabad has been attempting to find the most suitable cultivars for general cultivation. A huge collection was made from the blackgram growing area of Pakistan. Researchers took 10,000 single plants from potential area and out of these selected 1500 progenies on the basis of duration to maturity, plant type, yield potential and resistance to diseases (Anonymous, 1992-93).

Genetic improvement of any crop depends upon the nature and extent of genetic variability but also on the magnitude and inter-relationship of genetic and non-heritable variation in yield and its components. If such genetic variability is not available, plant breeder should have an idea of genetic diversity available in the initial breeding material. This will enable the breeder to plan a systematic hybridization programme for genetic improvement of crop under consideration. For an extensive hybridization programme, parent should be selected carefully that may lead to the development of superior yielding cultivars. The parents used in plant breeding generally fall in two categories. Locally released varieties which are selected from locally adopted germplasm and therefore, expected to contribute immediately to overall performance of the progenies and the varieties selected from a particular attribute without regard to local adaptation. This programme must set on sound foundation of extensive germplasm collection and continuous influx into progress so that populations are built up with high yield.

Conventional plant breeding methods have been effective in bringing about improvements but efforts are still being made to develop more efficient breeding methods to overcome specific problems. For example, the use of early generation yield data and statistics for the association of plant characters with yield have recently received much attention. Studies on bulk population breeding have shown that natural selection exerts a dynamic influence on the composition of the population at each generation, resulting in change in gene frequencies as the hybrid moves toward homozygosity (Adair & Jones, 1946; Suneson & Stevens, 1953). Pedigree and bulk population breeding are two classical methods used in handling hybrid derived from populations of self pollinated crops (Tee and Qualset, 1975). Dahiya *et al.* (1983) in chickpea, found linear relationship between F_2 and F_3, F_2 and F_4 and F_3 and F_4 generations in chickpea and indicated that selection and random selection are equally ineffective in the identification of high yielding lines.

The biometrical approaches such as multivariate analysis, estimation of genetic values, regression analysis, factor analysis, cluster analysis and combining ability studies by means of different mating systems have been shown to be useful in selecting parents and effecting crosses which generate populations as close as possible to the breeding target (Eberhart & Russell, 1966); Briggs and Shebeski, 1970; Sindhu *et al.*, 1989; Indu *et al.*, 1991; Kidambi *et al.*, 1991; Joseph and Santhoshkumar, 2000; Onkar *et al.*, 1993 and Lal *et al.*, 2001). Choice of the most efficient breeding procedure depends to a large extent on knowledge of the genetic systems controlling the characters to be selected {Pawar *et al.* (1985); Haddad and Muehlbauer (1981) and Rehman and Bhall (1985)}. Wide range of biometrical models is now available which estimate epistasis in addition to additive and dominance variation in self-pollinated crops. The concept of partitioning generation means was found to be one of the most potential biometrical tools available with the breeder to understand nature of gene action and to detect the type of epistasis mechanism operating in the expression of quantitative characters (Gill, 1965; Boerma and Cooper, 1975b; Bhatt and Derera, 1973; Parameswarappa & Patil, 1994: Patil *et al.*, 1998 and Rahman & Saad, 2000). The suitability of these techniques has not been adequately tested in genetic improvement programmes especially of self pollinated crops.

After getting adequate information regarding inheritance of yield and its components, component factors influencing yield, heritability estimates of the material under investigation, breeder has to fix certain selection criteria for isolating superior yielding lines in the early generations rather than following elaborate breeding procedures. Plant breeders are searching continuously for a more effective and efficient selection procedure. Numerous methods have been proposed on theoretical models but only few valid comparisons have been made among alternate procedures in early generations.

When intermediate phenotypes are selected at the expense of both extremes the selection is said to be stabilizing. When individuals near the mean are selected as parents or when a single optimum is favoured coinciding with the central phenotypes resulted in the reduction of genetic variance. When selection is practiced at both the extremes with intermating between extremes, selection is said to be disruptive. It is also referred as centrifugal selection. It brings about increase in genetic variance by favouring more than one optimum in a population.

Polymorphic monogenic traits were some of the earliest genetic markers employed in scientific investigations and they may still be optimal for genetic, breeding and plant germplasm management. Although morphological markers are limited in nature but their assays neither require sophisticated equipments nor complicated procedures. Monogenic or oligogenic morphological markers are generally simple, rapid and inexpensive to score (Ghafoor, 1999). Until, recently, scientific plant classification was based exclusively on morphological traits (Stuessy, 1990), some of which may serve as genetic markers suitable for plant germplasm management (Gottlieb, 1984; Hilu, 1984 and Stanton *et al.*, 1994). The association of QTL with easily identifiable markers could permit the rapid and precise identification and transfer of QTL into superior crop cultivars (Tanksley, 1983). The amount of information provided by marker based approach would depend on the type and number of markers, and their linkage relationship (Singh *et al.*, 1991; Singh and Singh, 1992).

Still, limited genetic information is available on blackgram, although it is a desirable food legume for tropics and sub-tropics. The reason for little genetic work is mainly due to lack of diverse parents with conspicuous morphological markers and difficulties in crossing the parents, few friar reports available so for on inheritance of qualitative traits (Sen & Jana, 1963; Ramaiah & Samolo, 1992; and Rao *et al.*, 1989). One of the uses of morphological markers is to detect QTLs for markers assisted breeding programe. The linkage studies for biochemical and morphological markers have been conducted by Kazan *et al.*, 1993 in chickpea; Zamir and Tadmor, 1984 and Muehlbauer *et al.*, 1989 in lentil; Weeden and Marx (1984 & 1987) in pea and Koening and Gepts (1989) in Phaseolus. They observed distorted ratios i.e., deviation from normal assortment (9:3:3:1) and considered it might be due to linkage for some alleles. The present studies was planned to investigate inheritance of qualitative markers, their validity in determining linkage if any for utilization in breeding programme.

The phenomenon of hybrid vigour has long been discussed but the real understanding varies from crop to crop, gene-action and parents involved (Zahid *et al.*, 1998, Ghafoor *et al.*, 2003 and Jha *et al.*, 1996). Study of heterosis will help in rejecting large number of crosses in early generations and selecting only those with high potential to advance desirable segregates in subsequent generations (Shinde and Deshmukh, 1989). It has been identified as a potential crop in most of the countries but its national average is one third of the potential yield (Ghafoor *et al.*, 1997). Being short duration crop, it has special advantage of growing during summer (July to October) and spring (April to June) season as well as in inter and multiple cropping systems. However, work on genetic information and varietal improvement of this crop has been rather limited.

It is a common believe among plant breeders that heterosis, superiority of hybrids over their mid parents, is proportional to genetic distance between their respective parents and varying degrees of hybrid vigour have been reported (Ghanderi *et al.*,1979; Solomon *et al.*, (1957); Bhatnagar & Singh (1964); Singh & Singh (1971); Singh *et al.*, (1975); Sagar & Chandra (1977); Arora & Pandya (1987); Malik *et al.*, (1987) and Ramanujam *et al.*, 1974). Even in the absence of epistasis, multiple alleles at a given locus could lead to either positive or negative heterosis (Cress, 1966). Selection of potential cross combinations should be exploited on the basis of manifestation of heterosis for varietal improvement (Joshi, 1979), if better diverse parents are chosen for hybridization (Ghafoor *et al.*, 2000).

Although, heterosis is exploited in most of the field crops, yet its usefulness remained unexplored in most of the legumes including blackgram mainly because of high degrees of self pollination (cleistogamous in nature) and lack of male sterile lines. Therefore, presence of heterosis can only be utilized in pulse crops for development of high yielding pure line varieties (Singh, 1971). Although heterosis for seed yield and its components have been investigated by Jahagirdar, 2001; Vikas *et al.*, (1999), Santha and Veluswamy (1999), Viswanatha *et al.*, (1998), Andhale *et al.*, (1996), Savithramma and Latha (1999), Bhor *et al.*, (1997) and Aher & Dahat (1999) in *Vigna* spp and varying degrees of magnitude have been also reported. But these results are mainly confined to F_1 only and no information is available for further generations. Therefore, same eleven crosses as involved in breeding method study were also evaluated for heterosis from F_1 to F_4 generations for further utilization of this material and information for crop improvement.

Objectives

The major objectives of this study were:

(i) To study the genetic basis of qualitative characters (pubescence, seed coat colour, presence of spot on the seed and pod colour), their validity in determining linkage, if any for utilization in plant breeding.

(ii) To compare three breeding methods i.e. {Pedigree Method, Single Seed Descent (SSD) and Bulk Method (BM)} to identify the most suitable for future application in blackgram improvement.

(iii) Identification of useful transgressive segregants for practical use in blackgram breeding.

(iv) To investigate extent and nature of hybrid vigour in blackgram to explore the possibility to use it in breeding methodology.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

2.1 *Breeding Methods*

Kalton (1948) suggested that neither bulk or pedigree methods of early testing for yield in soybean was reliable for estimating yield potential at least before the F_4 generation. The yield differences between parental varieties were a poor indication of bulk population, and yield performance of crosses in early segregating generations. The common breeding methods currently used in self pollinated crops are pure line selection, mass selection, backcross, pedigree, and bulk population breeding (Allard, 1960). Where crossing is involved and segregating populations are grown, the latter three methods are applied. These classical breeding methods are most efficient in terms of genetic gain per generation and per unit of time and it may not be advisable to evaluate large numbers of segregating populations (Bisen *et al.,* 1985). Generally, in most of the cereals crops like wheat, corn and barley several breeding procedures have been adopted, which helped to achieve considerable success. Weiss *et al.* (1947) studied, F_2 and F_3 bulk generations of soybean crosses and found that these two bulk generations were not sufficient to evaluate accurately the relative differences in agronomic performance among crosses. Frey (1954) observed significant difference in response to selection for yielding ability and test weight in F_3 populations of barley as compared to F_2 bulk. He further concluded that selection among F_2 population was effective.

Suneson (1956) developed an evolutionary method of breeding in which the bulk hybrid populations were grown in mass under competitive natural selection for 12 to 29 generations. The production gains achieved in these populations were comparable with those from the conventional and more costly breeding methods practiced in these days. Weber (1957) practiced selection of single plants superior for yield in three F_3 and F_4 bulks of hybrid soybean. Selections of similar maturing plants were made and these populations responded well to selection for yield. Panse (1957) stated that amount of improvement to be expected from selection depends upon mean values and genetic variability of population to which selection is applied. He further demonstrated that parental values cannot always be taken to give a reliable indication of F_2 performance in a cross as for instance in transgressive segregation.

Wright (1956) discussed the levels of selection, such selections among genes, cells, clones, biparental organisms within populations, between populations and among species. Lerner (1950) stated that selection is aimed at more than one character, different selection systems-independent culling levels, random selection and selection based on total score (selection index) is generally superior to all methods. Clayton *et al.* (1957) indicated that variability of response to selection is of utmost importance in experiments designed to compare different methods of selection. Given an observed difference between two unreplicated selection experiments, there is a question as to whether this represents a true difference or is merely a manifestation of sampling variability.

Torrie (1958) reported that selection effective for plant height, lodging index, bacterial blight reaction, oil and protein content of seed and iodine contents in oil and concluded that there were no differences among soybean varieties developed by either pedigree or bulk methods. Voigt and Weber (1960) conducted experiment on yield evaluation in F_4 generation lines derived from F_3 families of five soybean crosses. Yield evaluation in F_4 generation produced a greater number of lines exceeding the five percent level of probability above cross mean yield and fewer below than the standard bulk and pedigree methods. No significance differences were observed between F_5 mean yields of lines by bulk and pedigree methods. Although superior high yielding lines were obtained by all the three methods with suitable maturity, height and lodging resistance but the non-significant differences were observed for the component of variance due to selection methods and interaction of selection methods x crosses.

Computer simulation studies such as that of Gill (1965) would allow a more rapid estimation of variance of response with certain specified genetic models. Early generation selection for yield in wheat (*Triticum aestivum* L.) is desirable because a genotype possessing all of the desirable genes in either the homozygous or heterozygous condition occurs most often in the F_2, with its frequency declining in subsequent generations. Selection for yield potential using yield on single plants in early generations (F_2 or F_6) within crosses, however, has been ineffective (Shebeski, 1967; Briggs and Shebeski, 1970; and Knott, 1972).

Atkins (1964) practiced visual selection in F_2 generation for vigour, number of tillers, seed size and fertility to top and basal florets. He concluded that visual selection was somewhat more effective in identification of low yielding lines than it was for high yielding types. Brim (1966) proposed the modified pedigree method of selection for improvement of self pollinated crops. Grafius (1965) and Brim (1966) proposed a modification for the bulk population method which has become known as "Single Seed Descent". In this procedure, two or three random seeds are harvested from each plant in the bulk planting to form the seed source for the next generation. He also pointed out that Single Seed Descent (SSD) selection method is widely used in self-pollinated crops and offers several advantages, one being the high level of genetic variability that can be maintained among the lines of the population after successive generations of selfing. In other words, the SSD produces a better representation of the original population in advanced generations of selfing.

Hanson *et al.* (1967) developed a concept for improving a base population of homozygous lines of soybean through recurrent selection and intermating. The expected improvement in the base population resulting from intercrossing of superior lines was developed. Selecting the top 20 lines (5%) intermating and selfing in this study yielded a predicted a 235 kg per ha gain over the base population mean. Joshi *et al.* (1968) studied five crosses of wheat and found that selection of single plant as early as in F_2 is effective for high characters but not for the characters of low heritability such as grain yield and ear number per plant. In the F_3, selection on the basis of rows or plots was more reliable than single plant selection for characters of low heritability. Korsakov (1968) while studying genetic basis of soybean breeding reported that hybridization followed by individual selection may be started in the F_5 or F_6 or in the F_2. The individual selection is more laborious but gives resulted 2-3 years sooner. The selection for yield in the F_2 has given an effectiveness of only 12 percent compared with 22 percent in the F_3 and 40 percent in F_4. Similar results were obtained when selecting for plant height, large seeds and oil content of the seed.

McGinnis and Shebeski (1968) concluded that there is no advantage in selecting F_2 Plants for high yield, as no significant correlations were found between F_2 plant and F_3 line yields. Skorda (1973) selected F_2 Plants in closely planted populations on the basis of actual grain weight of each plant followed by replicated yield evaluation of the resulting F_3 lines. He concluded that it is possible to discard crosses based on F_3 performance.

Alessandroni and Scalfati (1973) found that selection for yield per head in spaced F_2 populations was effective in choosing the best yielding genotypes in F_4. Utz *et al.* (1973) concluded that efficient selection of grain yield based on yield components of individual F_2 plants and F_3 plant rows is not possible in the F_2 and F_3 generations.

Lupton and Whitehouse (1957) suggested the F_2 progeny and pedigree trials methods are to overcome the difficulty of selecting for yield in F_2. Grafius (1965) recommended the use of the Single Seed Descent method in order to evaluate F_2 genotypes in F_3 or F_4. Knott (1979) reported that F_3 selection based on a two replicate yield test showed a small increase (1.5%-3.8%) in yield over the Single Seed Descent procedure but the extra work involved was not justified. Numerous reports (Syme 1972; Bhatt and Derera 1977; Fischer and Kertesz 1976) have indicated that selection for harvest index can be effective in developing higher yielding cultivars of wheat. In a recent report Nass (1980) showed that harvest index had some potential as a selection tool in wheat breeding programme for Atlantic Canada. However, Whan *et al.* (1981) found using harvest index to be no more effective than selection for yield directly.

Pesek and Baker (1969) studied two stage tandem selection and index selection for the modified pedigree method of breeding self pollinated crops. They found that index selection was superior to tandem selection for all combinations of parameters simulated. The efficiency of tandem selection was increased substantially by selecting the most valuable trait first. The efficiency of index selection can be increased by more frequent estimation of selection index coefficients. Eberhart (1970) studied factors effecting efficiencies of breeding methods and on the basis of biometrical genetic studies reported that the efficient breeding programme must be based in the improvement of yield through random mating of varieties followed by recurrent selection. Briggs and Shebeski (1970) reported that a positive selection pressure of 10 percent resulted in a significant improvement in yield by visual selection in wheat. They also further concluded that when visual selection is used as a means of screening lines in a plant breeding programme, the intensity of selection should be low.

Roy and Murthy (1970) suggested a scheme in which selections are made in F_2 generation grown in favourable as well as stress environments. Further selections are made only in high yielding environments from F_3 lines with superior performance in both the environments. Fasoulas (1973) also recommended selection in the high yielding environment because its resolving power pronounced. The procedure of Roy and Murthy (1970) is entirely different from the one followed by Borlaug (1968) in wheat, where the material was grown and selected alternatively in diverse environments which enable the selections and identification of lines with wide adaptation and concluded that strains selected in alternate location in successive years starting at one location possessed wide adaptation. Stress environment differentiated barley strains better than non-stress environment.

Baker (1971) proposed as a modified pedigree selection for improving self pollinated species. Response is expected to be more variable with higher selection intensity or greater genetic variance and less variable with larger population size or decreased environmental variance. Response to selection has been observed to vary among replicated populations in many selection experiments. Falconer (1960) pointed out that no objective criterion existed for deciding how closely responses ought to agree. He further suggested that repeatability of response to selection was a problem of sampling variability.

Empig and Febr (1971) evaluated four methods of generation advance in bulk hybrid soybean populations. Single Seed Descent, Restricted Cross Bulk (RCB), and Maturity Group Bulk (MGB) maintained a similar number of high yielding lines about twice as many as in RCB. Single Seed Descent and MBG were no differences among methods for the efficiency of late segregants. SSD was about thrice as effective for maintaining large seeded lines as the other methods. They suggested SSD method to be most useful in green house or Winter Nursery environments. Boerma and Cooper (1975a) used a modified early generation testing procedure (selection based on combined generation means) was partially effective in identifying superior yielding F_2 derived soybean lines from which high yielding lines could be subsequently selected. Luedders *et al.* (1973) while comparing bulk, pedigree and early generation testing breeding methods in soybean observed that complete bulk and early generation methods retained a few more lines than Maturity Bulk (MB) and Pedigree (P) method.

Bhatt and Derera (1973) recommended a limited visual selection system in which single plant selection from F_2 to F_4 is carried out for most of the simply inherited characters, and when the progenies appear to be reasonably homozygous for these characters, lines derived from F_2-F_4 are bulked and carried forward as strains for yield trials. The resulting cultivars are relatively heterogeneous and may have an advantage in unstable environments. Townley-Smith *et al.* (1973) suggested that moving mean analysis was more effective in selecting high yielding plots than visual selection.

Hamblin and Donald (1974) demonstrated the value of plant morphological forms as a selection criterion in barley. A positive correlation of harvest index and grain yield within existing cultivars does not provide evidence of the value of harvest index as a selection criterion but there is some evidence that harvest index may have a real predictive value in certain situations. The analysis of single plant character showed that harvest index accounted for 71.7 percent of variability of the mean plot yields. The harvest index of spaced plants therefore tends to show lesser genotype x density interaction than does single plant grain yield and hence a better relationship to plot grain yield.

Shebeski and Evans (1973) while studying early generation selection for wide range adaptability in the breeding programmes considered that replicated hill trials with 40 or 50 seeds per hill, can be more efficient for selection than narrow plots and F_3 is the most efficient for selection than narrow row plots. Iyama (1976) conducted a computer stimulation experiment to investigate the effect of population size in each generation on the recovery of desirable recombinations in the F_1 generation was estimated under eight propagation schemes. The results indicated that small population size in the F_2 and F_3 resulted in loss of desirable genotypes. Boerma and Cooper (1975a) compared the relative effectiveness and efficiency of the three alternative selection procedures including Early Generation Testing (EGT), Pedigree Selection (PS) and Single Seed Descent (SSD) emerged as the most efficient procedure.

Tee and Qualset (1975) compare Single Seed Descent and Random Bulk (RB) methods in wheat and indicated that selection for certain highly heritable characters are practical in an accelerated generation program. The SSD and RB methods were generally comparable except for the important competition effect of plant height. Tall plants increased in the RB, changing gene frequencies significantly. In a system of rapid-generation turnover where only a few seeds per plant are produced the RB method can be applied more efficiently than SSD. Thus the RB method is recommended unless competition effects are important, whereupon Single Seed Descent becomes the preferred method.

Knott and Kumar (1975) compared early generation yield testing (YT) and Single Seed Descent (SSD) with Pedigree Method in different wheat generations. It was observed that the SSD lines were as good as the YT lines. The SSD procedure appears to have considerable merit. Donald and Hamblin (1976) suggested four selection criteria in the early generations for the improvement of yield by selection. It has long been emphasized that Single Plant Selection the basis of grain yield in early segregating population is ineffective as a means of developing high yielding pure lines in self-pollinated crops.

Roseilla and Frey (1975) demonstrated harvest index is the criteria for selection in the competitive environment may result in better grains. It seems evidences are needed to confirm the valuable criterion for early generation selection among spaced plants. They reported indirect selection for grain yield through harvest index would be only three percent as efficient (using grain yield as the selection criterion).

Knowles (1977) suggested a recurrent mass selection programme for the improvement of seed yield in intermediate wheat grass. Ivers and Fehr (1978) concluded that Pure Line Family (PLF) method generally would be a faster method for cultivar development than Bulk Family (BF), but the Bulk Family would be preferred when Recurrent Selection by early generation testing was feasible for improving character. Cultivar development with Pure Line Family would be faster than with Pedigree Selection. When winter facilities are available for generation advance, the PLF method may provide a large number of superior F_5 lines than SSD. However, it would sample less genetic variability and require more years, land, labor and record keeping than SSD.

Martin *et al.* (1978) studied the progenies from three soybean crosses advanced to four generations by Single Seed Descent in greenhouse. Plant losses averaged 19% of the original population at the low density and 55% of the original population at the high density at the end of four generations. It was observed that the progenies advanced from the high density population averaged 0.5 to 3.5 days later in maturity, 0.1 to 0.2 higher in lodging score, and 0.0 to 4.3 cm taller than progenies advanced from the low density population. Salmon *et al.* (1978) reported that pedigree selection and early generation yield testing procedures are equally efficient methods for yield selection in triticale.

McVetty and Evans (1980a) reported that use of physiological and morphological parameters alone or in combination on F_2 plants as selection criteria to identify high yielding F_4 bulk in wheat crosses. The result indicated that single F_2 parameters which described sources capacity sink capacity or plant morphological all identified high yield potential in the F_2; however, at 15% selection intensity only 17 out of 53 high yielding F_4 bulks were retained. McVetty and Evans (1980b) also reported the use of productivity, harvest index, and height in a combined index selection procedure on F_2 spaced plant as a selection criterion to identify high yielding F_4 bulks in three wheat crosses. The results indicated that a combined index selection procedure utilizing productivity, harvest index, and height may be useful in increasing yield in spring wheat. Qualset and Vogt (1980) accepted the concept that bulk population management may dictate different early generation treatment and recommended only 3 generations in bulk for a cross and suggested that the combination of pedigree and bulk hybrid population methods, with recurrent selection overtones, makes for a sound, efficient program.

Haddad and Muehlbauer (1981) advanced three lentil populations from F_2 to the F_4 generation by Single Seed Descent and Bulk Population (BP) breeding methods and compared the relative efficiency of the methods for maintaining genetic variation and selection opportunities. They observed that SSD maintained more genetic variation in 15 of 21 comparisons of characters that were made. They recommended that SSD method is an efficient cost-saving method of advancing lentil populations and recommended for lentil breeding.

Muehlbauer *et al.* (1981) compared Bulk Population (BP) and SSD methods, by computer simulation to determine which retained the most additive genetic variation after four generations of inbreeding in lentil. They observed that fecundity affected the genetic variability in BP, whereas the probability of individual plant survival was important in SSD. When the standard deviation of fecundity was greater than 25 seeds per plants, progeny from 75% of the original F_2 plants were not repeated in the population after four generations of advance by BP. About the same number of lines were lost after four generations when seedling survival dropped below 70% in each generation of advance by SSD. Linkage had little effect on additive genetic variance in either system.

Cooper (1982) stated that objectives of plant breeders are to develop varieties of high yielding ability, good quality and adaptation to different climatic environment and management systems. To achieve these objectives breeders must be able to identify the most appropriate selection procedures for the improvement of his crop. According to Sprague (1966) a realistic appraisal will often indicate that no one breeding system was completely adequate for a specific situation and that two or more systems should be used simultaneously. When this is true one system may be chosen because of simplicity and the promise of rapid improvement. The second method may be specifically chosen because of long range possibilities. Selection acts upon existing genetic variability and Its main function is shifting of gene frequencies (Rao & Singh, 1984).

Nass (1983) indicated that for grain yield there was no advantage of any of the selection methods over random selection in the low yielding cross 1 and no advantage of the harvest index and head weight method over visual selection in both crosses. Visual selection of plants or heads in F_2 populations for grain yield is at least as effective as other methods of selection and requires the least labor. In order to decide upon the most suitable selection method to use in selecting for grain yield in a cross, careful consideration should be given to the breeding objectives (height, disease resistance), the choice of parents (diversity), and the range of the F_2 generation expected (height).

Dahiya *et al.* (1984) investigated comparative evaluation of mass selection for seed size, pedigree selection and selection on yield *per se* for number of more productive lines with their production in green gram. The former was found the best method among these three methods. Mean seed yield/plant of 10% top yielding was also highest in case of small seeded progenies as compared to those of pedigree selection and selection on yield *per se*. Dahiya *et al.* (1983) conducted an experiment in which 4 F_3 were evaluated for yield in an F_3 yield trail and in single plant progeny rows. The lines from each of the four selection groups in each population were bulked and evaluated in a replicated yield trial at three sites and in four environments. The bulk of visually selected lines were not superior in yield to the bulk of locations. It is concluded that an early generation yield testing selection procedure is more efficient than visual selection for yield improvement.

Bisen *et al.* (1984) compared the effectiveness of three breeding methods for genetics improvement of seed yield in chickpea under two fertility levels and two spacing in two diverse crosses and reported that seed size bulk procedure proved to be consistent in varying environments as compared to yield bulk and single seed descent. Bisen *et al.* (1985) estimated realized heritability for seed yield in F_4 and F_5 generations from two crosses of chickpea. Three breeding procedures of all eight populations showed high estimates of heritability with the exception of seed size bulk in CS0 F_1. The realized h^2 estimates from different crosses and breeding procedures were quite inconsistent.

Dahiya and Singh (1985) reported that selection after two cycles of selective intermating was found to be a better method than traditional pedigree selection. It was suggested that selective intermating replace the widely adopted but less effective pedigree selection for generating promising new material in such autogamous crops as green gram. Dahiya and Singh (1986) also reported two cycles of selective intermating caused significant variation for all eight yield components studied, while a single cycle did not generate significant variation for number of seeds/pod or for seed yield/plant.

Islam *et al.* (1985) studied two wheat crosses, and reported that yield components (grain number/spikelet, grain number/ear and grain weight) had narrow-sense heritabilities ranging from 32 to 90%, while the value for yield/plant was zero. Single F_2 plant selection for grain number/spikelet and grain number/ear, increased yield/plant in the F_3. Selection for grain weight increased grain weight in both crosses, but in one there was a decrease in yield/plant, resulting from a reduction in grain number/ear. Selection for yield/plant did not give any appreciable response.

Lungu (1985) compared honeycomb selection for yield in F_2 and F_3 generations in two crosses for effectiveness in identifying high and low yielding lines. F_3 plants from high yielding F_2 selections gave higher yields than those from the low yielding F_2 selections by 12.1% and 13.8% respectively. The F_4 generation yield test gave similar results. High yielding selections from both crosses significantly outyielded than low yielding selections and the unselected composite lines. Intergeneration correlations between F_3 and F_2, F_4 and F_3, and F_4 and F_2 yields were all positive and significant. The use of both path coefficient analyses and offspring-parent stepwise multiple regression analyses were successful for identifying yield components for selection in segregating generations.

Salimath and Bahl (1985a) recorded data on seed yield, pods/plant, seeds/pod and 100-seed weight in 21 F_2 populations derived from 7 parental lines crossed in all possible combinations excluding reciprocals. High heritability (86.16%) for 100-seed weight was observed. Only number of pods/plant was positively correlated with seed yield. In another study they suggested direct selection to improve each yield component. Salimath and Bahl (1985b) studied by applying a 5% selection pressure separately for seed yield, pods/plant, seeds/pod and 100-seed weight in 21 F_2 populations, 4 groups, each of 84 F_3 progenies. Comparison of the 4 groups indicated that the one derived by selecting for seeds/pod provided the best opportunity for improving seed yield.

Pawar *et al.* (1985) compared three selection methods Single Plant Selection (SPS), Single Seed Descent and Bulk Selection in two wheat crosses. Mean performance of ten populations indicated superiority of selected populations over other populations. The generation mean analysis, on the whole, indicated the preponderance of additive gene effects for almost all the characters. The SSD method was found better than Bulk Population breeding. The inter-generation phenotypic correlation coefficients between F_3 parent plants and F_4 progenies were significant for most of the characters in both crosses. Prasad and Ram (1985) suggested that Bulk Population method and breeding would be more effective method in breeding for more number of pods/plant in F_2 generation of French bean. They also recommended SSD as least influenced by natural selection. Dahiya *et al.* (1987) compared SSD selection and SPS and showed the superiority of earlier over the latter as selection method for the production of high yielding progenies, maintaining the high variability and for handling the segregating material in mungbean.

Rahman and Bahl (1985) compared Single Seed Descent (SSD), Mass Selection (MS) and Random Bulk (RB) methods in F_3 and F_4 chickpea for grain yield and some other components. They concluded that MS excelled RB and SSD in chickpea breeding. Of the RB and SSD methods, though both were equal in performance, the latter may be preferred in chickpea because of saving in time, space and labour. Rahman and Bahl (1986) analysed data of 6 crosses and revealed that intergeneration correlation values for mean plant height, seed number/pod and 100-seed weight were higher between generations F_3 and F_4 than between generations F_2 and F_3 or F_2 and F_4. It is suggested that selection in the F_3 might be beneficial for these traits. However, the correlation values for pod number/plant and seed yield were mostly not significant.

Singh and Smithson (1986) studied the assessment of F_2 derived lines as a breeding procedure in chickpea and found that F_2 derived lines as a breeding procedure could prove useful in breeding self pollinated crops such as chickpea to heterogeneous and thus more stable lines for further selection. Instead of expansion to large numbers as in normal pedigree procedure, the greatest volume of material is in F_2 and F_3 stages and from there on it rapidly reduces. Molari *et al.* (1987) advanced F_2 plants from the soybean cross to the F_6 by SSD without selection. The F_6 lines selected from F_3 individuals had yields equal to those of the best lines of the whole SSD population, suggesting that population size may be safely reduced by early generation selection. Selection for earliness was effective on both an individual and a family mean basis. It was also suggested that selection for yield should be based on a related characters of simpler genetic control, such as pods/plant.

Katiyar *et al.* (1981) indicated that pods per plant had the highest direct effect on yield of chickpea but overall positive correlation between pods per plant and seed yield was reduced by a high negative indirect effect of pods per plant on seed yield via seeds per pod. Similar associations were also reported by Khan *et al.* (1983). Salih (1982) found very little associations among seed size, the number of pods/plant, seeds/plant, and plant height in chickpea. Pandya and Pandey (1980), investigation revealed that seeds/plant had a positive and high association with number of pods/plant, number of branches and days to flowering and very little association with 100 seed weight, while plant height showed negative correlation with seed yield. Such studies were carried out mainly with pure lines and similar information for segregating populations is limited. Ram *et al.* (1980) studied the segregating populations in chickpea and reported that pods and seeds per plant consistently showed the highest positive direct effect on seed yield in F_2 and F_3 generations in all the crosses studied.

Obisesan (1987) carried out visual selection in the F_2-F_4 of 3 crosses involving four varieties. Selection had a significant effect on pods/plant but not 100-seed weight. Only one selected F_3 bulk outyielded the unselected F_2. It is concluded that use of a selection index could give faster and better results, in view of the failure of visual selection to give higher-yielding material. Pushpendra and Ram (1987 and 1988) studied a total of 400 F_2 plants from two crosses were scored for pods per plant, harvest index and seed yield. Comparison of means, upper limits of range, genetic advance, proportions of superior or significantly superior progenies in selections vs. those in bulks indicated that selection for seed yield per plant and harvest index in early generations (F_2, F_3 and F_4) of the crosses was ineffective. However, selection for number of pods per plant was relatively effective.

Sharma *et al.*, 1987 exercised selection for harvest index on single plant basis in F_2 and F_3 generations in wheat crosses and observed a wide spectrum of variability for harvest index and associated characters. Their study clearly suggests that the usefulness of harvest index as a selection criterion over direct selection on grain yield. Bisen *et al.* (1988) studied Single Seed Descent, Yield Bulk and Seed Size Bulk in two crosses of chickpea advanced under two fertility levels, two spacing and at two locations. High magnitude of G X E interactions were observed for seed yield and seed size. The variability in seed yield can be exploited through variation in seed size, by selection of the segregating material under different environments and locations. Selection for seed size proved efficient for high yielding lines with considerable range of variation for this character.

Cooper (1990) described a modified early generation testing procedure in which the number of yield test plots required/cross was reduced from 1860 to 175. This modified early generation testing procedure has been used in soybean breeding programme since 1972, resulting in the release of 8 high-yielding cultivars. Saini and Gautam (1990) examined individual F_2 progeny from 10 crosses and were classified as high, medium or low yielders. A total of 150 F_3 and 150 F_4 families from these plants were evaluated for yield and 10 related characters under normal and late-sown conditions. Correlations were observed between the performance of F_2 plants and F_3 families under the late-sown condition and between F_3 and F_4 families under both conditions, indicating the effectiveness of early generation selection in generating material suitable for both normal and late-sown conditions.

Singh *et al.*, 1990 evaluated F_3 to F_5 generations from the two crosses in mungbean produced by Single Seed Descent (using 3 spacing) or the Bulk Method, for days to maturity, number of branches and seeds per pod. There was no evidence for a directed shift in mean performance for these traits. Estimates of heritability and genetic advance were moderate to high, indicating the possibility of improvement through selection, and did not differ significantly between the different breeding methods. Sood and Gartan (1990) investigated pure breeding *Vigna mungo* lines, and the F_1 progeny and parents grown in a randomized complete block design, with inter-row spacing of 30 cm and plant spacing of 10 cm, for recording of data on various yield-related traits. Additive genetic variance was significant only for plant height, while the dominance components H1 and H2 were significant for all characters, indicating the importance of both additive and dominance types of gene actions in inheritance of plant height. For other traits such as primary branches/plant, pods/plant and seed yield the dominance component prevailed. Pedigree breeding methods are seen as more useful where the dominance component is the major factor, while repeated back-crossing is recommended where both additive and dominance components prevail.

Byron and Orf (1991) compared three selection procedures (Pedigree, SSD and SSD with early maturity) for development of early maturing soybean lines. No consistent differences were apparent among the selection procedure for maturity, height, lodging, seed weight, or length for two periods. Because it required the least resources, the SSD with Early maturity procedure emerged as the most cost effective procedure. Yadav, 1990 indicated that yield was significantly correlated with number of seeds/plant, number of pods/plant, number of secondary branches, pod bearing length, 100 seed weight and plant height in F_2 chickpea segregating population. Similar results were reported by Arshad *et al.*, 2002 & 2003 in advance chickpea genotypes.

Branch *et al.* (1991) compared Pedigree, Sequential Selections and SSD for yield and leaf spot resistance in peanut for three years and proposed a sequential selection method proved to be an alternative approach for peanut breeding and to minimize genotype X environment interactions. Indu *et al.* (1991) studied an F_1 half-diallel cross of 5 *Lens culinaris* parents, additive and dominance gene effects were important for number of days to flowering, height and days to maturity, with additive effects predominating.

Dominance effects were more important for primary and secondary branches/plant, pods/plant, seeds/plant, seed/pod, biological yield, seed yield, 100-seed weight and harvest index. Kidambi *et al.* (1991) derived estimates of genetic variance for 3 chickpea (*Cicer arietinum*) crosses involving parents with diverse yield characteristics. Seven generations (P_1, P_2, F_1, F_2, F_3, BC_1 and BC_2) were evaluated for 4 yield components. Heritability estimates were moderate for all yield components measured except yield/plant. Singh and Singh (1991) derived information on genetic variance and combining ability from data on seed yield and 8 yield-related traits in 5 diverse lentil cultivars and their 10 F_1 hybrids. Two cultivars were good general combiners for 100-seed weight and seed yield/plant, respectively.

Charumathi *et al.* (1992) conducted study on dry seeds, treated with gamma-rays. For the characters days to 50% flowering, days to maturity, and plant height, selection was confined mostly to the M_2 generation while comparing M_3 generation with the M_2, variation was greater for number of branches and pods/plant, pod length, seeds/pod, seed yield/plant, 100-seed weight and protein %age. Some desirable micromutational progenies for early maturity, more branches per plant, high pod and seed numbers and bold seed were isolated in the M_3. Chaudhary *et al.* (1992) derived information on genetic variance in 22 pure breeding lines of adzuki bean (*Vigna angularis*) raised as a triple test cross. Epistatic, additive, dominance and ambidirectional dominance gene effects were observed for the various traits. Mishra *et al.* (1992) studied sixteen F_2 populations of two crosses of rice for yield, 100-grain weight, panicle bearing tillers and grains/panicle in F_2 population. They found that selection based on a single component was effective in succeeding generations.

Obisesan (1992) conducted study on three crosses to assess the effectiveness of 2 selection procedures, namely Pedigree Selection (PD) and Single Seed Descent selection (SSD). Lines developed by each procedure were yield tested and selected at F_6 and F_7 for PD and SSD respectively. The selected lines for both procedures were compared at F_8 for grain yield/plant, pods/plant and pod development period at 2 locations. Both procedures have been effective in producing superior genotypes for yield and number of pods. The PD method produced superior transgressive segregants in 2 of the 3 crosses for pod development period. Single Seed Descent allowed a more rapid generation than PD.

Kumar and Bahl (1992) studies showed that five selection methods resulted from application of 10% selection intensity from F_2 to F_5, for pods per plant in SP1, seeds per pods in SP2, seed weight in SP3, seed yield in SP4, and random selection in SP5. The result indicated that the selection method has profound effect on association patterns and there is possibility of breaking undesirable correlations. Biradar *et al.* (1993) gave information on heritability and genetic variance in 2 indigenous cowpea lines, grown with their F_1, F_2 and backcross generations. Additive gene effects were important for most traits. The predominance of additive genetic variance, coupled with high heritability and genetic advance for most yield components indicated good potential for improvement by selection.

Singh and Singh (1993) evaluated F_2 to F_5 progenies of lentil for number of pods/plant and seed yield. The F_2 data showed the highest yield in one cross; was consistently higher yielding than any of the low yielding crosses in the later generations. The results suggest that crosses with high mean seed yield in the F_2 or F_3 may be used to produce high yielding lines in advanced generations. Patil *et al.* (1994) studied the efficiency of early generation selection for yield and related characters in safflower (*Carthamus tinctorius*) in the F_2, F_3 and F_4 generations. In the F_2 generation, capitula/plant (CNSP), seeds/capitulum (SPSP), test weight (SWSP) and seed yield (SYSP) were the criteria used for single plant selection. Analysis of variance showed significant differences for all of the characters in the F_2, F_3 and F_4 generations and values in each of the selection classes showed highly significant genotypic differences. In each class the mean for that particular character showed a positive shift. They observed F_3 and F_4 means for seed yield/plant was higher in SYSP, indicating the effectiveness of single plant selection for yield. Correlated response showed that selection for capitula/plant was effective for improvement of yield.

Ranganatha *et al.* (1994) reported that F_3 yield testing was a reliable indicator of the performance of progeny in subsequent generations of sesame. The intergeneration correlations and heritabilities revealed that early generation testing was not a reliable indicator of the performance of progeny in subsequent generations, while it could be reliable to a considerable extent for maturity. Early generation yield testing was also concluded unworthy considering the time, labour and resources required in sesame.

Saadalla and Fasoulas (1994) compared the response to direct early-generation selection for yield to indirect yield selection via its components using Fasoulas' honeycomb design to select among F_2 plants in two crosses of spring wheat. It was concluded that modified early-generation selection using Fasoulas' design to reduce environmental variation among F_2 plants and selecting for heavy grains is effective in improving wheat grain yield.

Sharma and Gupta (1994) evaluated 32 breeding lines from an urdbean x mungbean cross. Seed yield was correlated with biological yield/plant, harvest index, clusters/plant, pods/plant, plant height and 100 seed weight. Path analysis showed that biological yield/plant had the greatest positive direct effect on seed yield, followed by harvest index, pods/plant, seed sulfur content, days to maturity, days to flowering, clusters/plant, 100SW and pod length. Seeds/pod, seed phosphorus content, seed crushing hardness, plant height and protein content had negative direct effects on seed yield/plant.

Singh *et al.* (1994) estimated yield correlation and path coefficient analyses, using data obtained from the evaluation of F_1, F_2 and F_3 generations resulting from 5 crosses between 3 green gram and 3 blackgram cultivars as well as the parents for 7 yield components. Plant height, pod length, pods/plant, biological yield/plant and harvest index were positively correlated with seed yield/plant. Path coefficient analysis revealed that harvest index, biological yield/plant and pod weight/plant had a direct positive effect on seed yield/plant. Hepziba and Subramanian (1994) studied genotypes Vamban 1 and ADT3 that were irradiated with 20-90 kR gamma rays. Forty families of each genotype in the M_3, and 20 and 40 families of Vamban 1 and ADT3, respectively, in the M_4 generation were evaluated for 8 yield components. Pods/plant exhibited high variability at both the phenotypic and genotypic levels. Results indicated that environmental influence on the measured traits was low. High heritability coupled with high genetic advance was recorded for seed yield/plant, number of clusters/plant and pods/plant.

Singh *et al.* (1994) conducted experiment on three F_2 crosses of chickpea in late sown conditions. Three selection methods were carried out, (random selection, visually superior selection and selection based on yield). Fifty F_2 plants were retained under each selection method and in next year progenies were evaluated for seed yield. The results indicated the superiority of selection based on yield, followed by the visual selection, it is suggested that visual selection on the basis of important yield components should be practiced, possibly followed by yield observations at some later generation.

Rehman *et al.* (1995) studied selection criterion for high yielding urdbean genotypes and recommended that seeds per pod and pods per plant were used as a selection criterion to established high yielding genotypes. Gill *et al.* (1995) studied the comparative efficiency of four selection methods, viz., Honeycomb (HC), Pedigree Selection (PS), Single Seed Descent (SSD) and Bulk Method (BM), in three mungbean crosses. On the basis of the mean, range, the number of superior lines over the best control and the proportion of the top 10% lines in all the crosses and generations, the HC exhibited superiority over PS, SSD and BM for yield per plant and its component traits. Pedigree Selection, SSD and BM did not differ from each other. The HC and SSD methods were found suitable for deriving superior lines for seed yield and pods/plant in mungbean.

Mehla *et al.* (1995) studied four chickpea crosses grown under late sowing conditions. The F_2 progenies originating from single plants selected, using visually superior, yield *per se* and random selection methods were evaluated. Analysis of variance indicated significant differences among the progenies within a cross, within a method and among the methods. The best selection method was observed to be yield *per se* followed by visual and random selection methods based on progeny means, number of superior progenies over the control and on the basis of the top yield progenies.

Comstock (1996) suggested that for plant breeding programs, it is also necessary to maintain the genetic base of the population as widely as possible to avoid bottlenecks that are an important cause of reduced genetic variability. It is important to recall that fixation of favourable alleles by recurrent selection does not depend exclusively on heritability, gene action, initial allelic frequency, and selection intensity; it is significantly determined by the effective population size (N_e) maintained throughout selection cycles.

Kant and Singh (1997) studied ten F_2/F_3 populations generated from crosses of exotic lentil lines and were evaluated under timely and late-sown conditions. They observed frequency of transgressive segregants for earliness. Ranjan X K-75 was the best cross for timely sown conditions, and Precoz X Pant L-406 was the best cross for late-sown. Salimath *et al.* (1997) also investigated genetic variability and transgressive segregation in 6 yield related traits in the parents and F_2 and F_3 progeny from the chickpea grown during the post rainy season.

Nagarajan and Rangasamy (1997) evaluated some 486 lines from 202 families of green gram x blackgram. There was a high magnitude of variability for plant height, number of pods/plant, seed yield, number of clusters, number of branches and pod yield. Moderate variability was found for pods/cluster, pod length, seed/pod and root length. The following highly significant and positive associations were identified: seed yield with pod per cluster and pod yield; pod yield with number of pods; plant height with seeds per pod; and number of branches with pod length and root length.

Singh (1997) gave a review on the origin and botany of *Cicer arietinum* and major achievements and goals in breeding for specific agronomic characters and resistance to diseases, insect pest, drought, cold and iron deficiency. The F_2 derived family, bulk pedigree and two cycle selection breeding methods are outlined. Over 50 cultivars were developed for sowing in the Mediterranean basin and for rice fallow in South Asia. Singh and Singh (1997) tested reliability of individual plant selection for grain yield, plant height, effective tillers, days to maturity, grain/spike, kernel weight and harvest index in five F_2 populations of bread wheat. Plants were selected for each of the seven characters in positive and negative directions in F_2 plants and the selection response was determined in F_3 plants. Significant inter-generation correlation coefficients and moderate to high realized heritability estimates were observed in three of the populations for kernel weight and kernel weight, indicating that individual plant selection for plant height and for kernel weight was effective.

Fahim *et al.* (1998) compared the efficiency of four breeding methods (Pedigree, Modified Pedigree, Bulk Method and SSD) in different generations in two crosses of rice. The results showed that SSD is at least as effective as the other methods; is less costly and, where three generations can be raise/annum, is more rapid. It was also observed in this study that every one of these methods, therefore, has been successful in identifying and extracting superior transgressive segregants from these crosses.

Kant and Singh (1998) conducted study on experimental material consisting of 13 diverse lentil parents, 30 F_2 and F_3 bulk populations. None of the crosses showed transgressive segregates for 100 seed weight in the F_2 generation. E-258 x Pant L-234 exhibited the highest frequency of transgressive segregates in the F_2 generation for yield/plant (47%), followed by E-158 x K-75 (33%) and E-153 x Pant L-234 (27%). These crosses also had high frequency of transgressive segregation in the F_3 generation for yield/plant and pods/plant. The highest numbers of transgressive segregates in the F_3 generation for yield/plant were observed in crosses of IC78013 and IC78415 with the testers. Three indigenous crosses were promising because in addition to yield/plant transgressive segregation for important yield components was also observed in both the generations.

Mehta and Zaveri (1998) studied three selection methods viz., Pedigree Selection (PS), SSD and Mass Selection (MS) in F_5 generation of *Vigna unguiculata*. Seed yield/plant was strongly and positively associated with branches/plant, clusters/plant and in all the three selection schemes. Results revealed the superiority of SSD over PS and MS schemes for the production of high-yielding progenies, for the maintenance of high variability and for handling the segregating materials.

Sajikumar *et al.* (1998) evaluated thirty blackgram genotypes. Genetic analysis revealed the existence of considerable genetic variability among these genotypes. Genotypic correlation was highest between number of pods/plant and number of clusters/plant followed by weight of pods and grain yield/plant which implies that indirect yield improvement is possible through these characters. Singh and Singh (1998) evaluated seven yield components in F_3 and F_4 generations derived from a cross between mungbean and blackgram. Seed size of F_3 and F_4 (2.7-2.8g/100 seeds) plants was significantly lower than the parents of F_3 and F_4 plants and were superior to parents for the other yield components examined. Overall, all characters except for 100-seed weight exhibited a wider range of variation in F_3 and F_4 hybrids, with a high frequency of plants expressing extreme phenotypic variation in segregating population.

Singh *et al.* (1998) derived segregating populations from 18 simple crosses and the same number of top crosses from two parents (Veery #10 and Yecora 70). The four selection schemes were: Pedigree, Modified Bulk (F_2 and F_1-top as Pedigree, selected lines in F_3, F_4, F_2-top, F_3-top as Bulk; and Pedigree in F_5 and F_4-top populations), Selected Bulk (selected plants in F_2, F_3, F_4, F_1-top, F_2-top and F_3-top as Bulk; and Pedigree in F_5 and F_4-top populations), and Non-Selected Bulk (Bulk in F_2, F_3, F_4, F_1-top,

F_2-top and F_3-top; and Pedigree in F_5 and F_4-top populations). A total of 320 progeny lines, parents and checks were tested for grain yield, other agronomic traits. The influence of the type of cross and the selection scheme on the mean grain yield and other traits of the progenies were minimal. Moreover, the highest yielding lines were distributed equally. Progeny lines derived from Veery #10 crosses had significantly higher mean grain yield compared to those derived from the Yecora 70 crosses. Furthermore, a large proportion of the highest yielding lines also originated from Veery #10 crosses. Selected Bulk appears to be the most attractive selection scheme in terms of genetic gains and cost efficiency.

Singh *et al.* (1998) evaluated fifteen F_3 bulks, derived from reciprocal crossings of 6 lentil (*Lens culinaris*) varieties, and one control variety. Harvest index coupled with pods/plant and primary branches were reliable selection criteria in segregating generations for increased yield. Harvest index and pods/plant in conjunction with secondary branches were helpful in selection for yield. Random bulk procedure of generation advancement in the F_2 was unable to identify plants with increased yield in the F_3 and yield per se could not be used as a reliable criterion for rejection/selection of crosses in the F_3.

Ghafoor (2001) evaluated 484 germplasm accessions of blackgram for qualitative and quantitative traits. The investigated germplasm displayed a wide range of diversity for most of the traits along with some accessions with unique characters which could help to identify landraces with suitable traits to be used in hybridization programme for breeding to broaden genetic base. Ghafoor *et al.*, 1993 also gave emphasis for the selection of legume genotypes on the basis of high harvest index. Arshad *et al.*, 2002 reported high amount of genetic gain for earliness, grain yield and 100 seed weight and suggested to use better parents to have the best combinations for sustainable utilization of genetic resources without losing genetic diversity in blackgram. St. Martin and Geraldi (2002) studied the effectiveness of testing F_1-, F_2- and F_3-derived families in soybean. The three early generation treatments produced similar genetic gains in seed yield, averaging approximately 4%. They recommended testing F_2-derived families, unless off-season nurseries permit development of F_3-derived families without further loss of time.

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Joshi and Witcombe (2002) compared two participatory approaches i.e., farmer managed participatory research (FAMPAR), was researcher intensive and informal research and development (IR & D), demanded fewer resources to varietal selection in rice in 18 villages in high potential production system. Both participatory approaches identified the same varieties. But, FAMPAR, which used formal survey methods, was more useful for diagnosing reasons for adoption or rejection. However, IR & D used much cheaper anecdotal methods of evaluation and farmer to farmer seed dissemination was also higher, so it is more cost effective. The benefits from both approaches were considerable, but with certain limitations.

Vencovsky and Crossa (2003) reviewed some measurements of representativeness such as the effective population size (N_e) useful in genetic resources conservation and plant breeding research. They pointed out that while comparing effective population sizes for the SSD method vs Bulk System, results showed that SSD maintains genetic drift at a low level and offers a much better protection against random loss of alleles during selfing generations. Estimating population parameters, through codominant genetic markers is fundamental for obtaining reliable estimates of effective population size.

2.2 Inheritance of Qualitative Traits

Polymorphic, highly heritable morphological traits were some of the earliest genetic markers employed in scientific investigations (Mendel, 1866; de Vries, 1912), and they may still be optimal for çertain plant germplasm management. Morphological assays generally require neither sophisticated equipment nor preparatory procedures, so monogenic or oligogenic morphological markers are generally simple, rapid and inexpensive to score. Until, scientific plant classification was based nearly exclusively on morphological traits (Stuessy, 1990), some of which may serve as genetic markers (Gottlieb, 1984; Hilu, 1984) suitable for plant germplasm management (Stanton *et al.*, 1994). Pathak and Singh (1943) observed a 3:1 ratio for blackish to brown coloured pod in green gram. Hayman, (1954) and Griffing, (1956) with a Principal Component Analysis, to divide the parental lines into groups sharing similar genetic control for the traits studied. We found that the two main groups, defined according to their genetic control of node of first flower, also differed for all the other characters and, in particular, did not reach the same levels of productivity. These results indicated that crosses within the group with the highest productivity, but between lines with differing development and architectural features, could be a good starting point for breeding high-yield pure lines. Picard (1963) stated that seed coat colour is the most stable and less influenced by environmental factors and its simple genetic inheritance has been ascertained. He also found that green and black colour were recessive and dominant respectively in faba bean.

Sen and Jana (1963) studied the inheritance of pod colour in blackgram and found that black pod colour is dominant over straw colour and the character is controlled by a single gene. Whereas, Ramaiah and Samolo, (1992) reported two complementary genes for controlling pod colour in blackgram. Sen & Ghosh, (1959) reported complementary interaction for pod colour (3:1 ratio) in green gram, whereas, Chaudhari & Thombre, (1975) observed single gene dominance for pod colour in pigeonpea. Inheritance of prostrate growth habit, simple leaf type and thick stem was studied in chickpea by Singh & Singh, (1992) where all the characters observed were monofactorial recessive inheritance.

Jindla and Singh (1970) conducted studies on C34, which had violet flowers, hastate leaves and short pods, was crossed with C85, which had very light violet flowers, rhomboid leaves and long pods. Violet flowers were dominant over very light violet. Hastate leaves were dominant over rhomboid leaves. Four genes were involved in the control of leaf shape; LS1 was "essential", while any two of LS2, LS3 and LS4 resulted in hastate leaves. Partial dominance was observed for pod length, which appeared to be under multiple gene control. Aryeetey and Laing (1973) inheritance of yield components was studied in a cross between two varieties, and the relationships among the components and yield were examined in the F_2 of a cross and in a trial of 22 varieties. All the components appeared to be under polygenic control and transgressive segregation in the F_2 was observed for pod length and seed number per pod.

Leleji (1975) studied seed size, number of seeds per pod and pod length in seven crosses. In crosses between large and small-seeded parents, small seeds were partially dominant and broad-sense estimates of heritability ranged from 49 to 82%. Hanchinal and Goud (1978) while studying the F_1 and F_2 of the cross *V. unguiculata* sub sp. *sesquipedalis* 'Selection 2' X sub sp. *sinensis* 'Iran Grey', observed that the colour of the unripe pods and of the flower buds was governed by the same two pairs of genes, one gene being responsible for colour production and the other being inhibitory. A common gene was responsible for the production of flower and seed-coat colour. However, flower colour showed monogenic inheritance, a supplementary gene was apparently involved in the determination of seed-coat colour.

Ladizinsky (1979) investigated seed coat colour in lentil and reported single gene for seed coat spotting. He found 3:1 ratio of F_2 plants with spotted and non-spotted seed coat and proposed the symbol *Scp* for the gene controlling seed coat colour. He also found that pod indehiscence was controlled by a single recessive gene and assigned the symbol *pi*. The segregation in back cross also confirmed the findings of F_2 generation. Pathak & Singh, (1943) observed 3:1 ratio for blackish to brown colour in green gram. The flower colour in peanut has shown incomplete dominance that segregates in a ratio of 1 (red):2 (intermediate red):1 (yellow) by Habib *et al.* (1980), whereas, genetics of testa colour expression has been reviewed by Wynne & Coffelt, (1982) and Senapathi & Roy, (1990) who reported seven loci involved in the expression of testa phenotypes.

Baker (1981) studied inheritance of seed coat colour in eight F_2 spring wheat cultivars and find out that single gene was responsible for red seed coat colour in two parents while other two parents carried two genes and three other parents possessed three genes for red seed coat colour. Ricciardi *et al.* (1985) observed that 'Spotted' seed colour was dominant over any uniform seed coat colouring in broad bean. Brown was dominant over black, green and normal (beige colour). Black and red seed parents behaved as recessive in all F_1 progenies. A 3 (coloured): 1 (normal) segregation ratio was observed in all the F_2 of cross of 'violet', 'brown', 'black', 'red' and 'spotted' seed coat parents to 'normal' seed coloured parents. Green x beige gave a segregation ratio of 9:7 in F_2. When two parents with different seed coat colour were involved in a cross, the F_2 showed a typical digenic segregation ratio, thus demonstrating two unlinked and sometimes epistatic loci.

Dasgupta & Das, (1987) investigated inheritance of pod length and cluster number in blackgram and observed wide genetic variability for these characters in two crosses, hence, suggested selection of desirable segregants for improving cluster number and pod length. Waldia and Singh (1987) investigated inheritance of dwarfing gene in F_1

in pigeonpea and observed that the dwarf phenotypes were governed by 2 recessive genes. A ratio of 15 (tall): 1 (dwarf) was observed in the F_2 of all the three crosses. Kaushal and Singh (1988) identified that resistance in both Pant U 19 and Pant U 26 was monogenically controlled but different genes were involved in the 2 cultivars. Havey and Muehlbauer *et al.* (1989) studied a genetic linkage map of lentil comprising 333 centimorgans (cM) was constructed from 20 restriction fragment length, 8 isozyme, and 6 morphological markers segregating in a single interspecific cross (*Lens culinaris* x *L. orientalis*). They observed segregations for RFLP, 5 of 8 isozyme, and 5 of 6 morphological markers fit the expected F_2 ratios of 1:2:1 or 3:1.

Rao *et al.* (1989) reported monogenic recessive inheritance of multifoliate leaf in blackgram. The linkage studies for biochemical and morphological markers have been conducted by Kazan *et al.* (1993) in chickpea; Zamir & Tadmor, (1984), Weeden & Marx, (1984, 1987) in pea and Koenig & Gepts, (1989) in Phaseolus. They observed distorted ratios i.e., deviation from normal assortment (9:3:3:1) and considered it to be due to linkage for some alleles.

Vandenberg and Slinkard (1990) reported that the background colour of lentil seed coats is controlled by two genes. Dominant *Ggc* determines gray ground colour while the dominant *Tgc* gene produces tan ground colour. When both dominant genes are present (*Ggc Tgc*), brown seed coat colour is produced. The double recessive for these genes (*ggc tgc*) has a green coat colour. They also reported that dominant allele of *Glp* produces pod pubescence while the homozygous recessive allele (*glp*) produces glabrous pods in lentil. The dominant *Grp* gene produces red while the homozygous recessive *grp* allele produces green pods.

Kabir and Sen (1991) investigated the genetic control of plant growth habit and stem pigmentation in Lablab bean. The plant growth is controlled by two genes having complete dominance at each locus with recessive epistasis interaction of gene over the other. Anthocyanin pigmentation of stem is also determined by two genes. One of the two genes controlling this character showed partial dominance and epistasis in recessive homozygous state for the other gene. The green stem is also determined by two genes which in recessive homozygous state produces the typical green phenotype. Biradar *et al.*

(1995a and 1995b) also conducted studies on inheritance of seed weight, protein content, flower colour and seed coat colour pattern in cowpea (*Vigna unguiculata*).

Hegde *et al.* (1996) studied the nature of gene action and heritability involved in the inheritance of powdery mildew (*Erysiphe polygoni*) resistance in an intervarietal cross in mungbean (*Vigna radiata*). Additive and additive-based gene interactions played a major role in the inheritance of powdery mildew resistance. The resistance showed high heritability. Saleem *et al.* (1998) studied six elite lines of mungbean (*V. radiata*), 2 local and 4 exotic and their crosses were studied for the inheritance of resistance to mungbean yellow mosaic gemini virus (MYMV). The F_2 populations segregated into 3 susceptible and 1 resistant lines, suggesting that susceptibility and resistance were controlled by a single genetic factor. It is suggested that susceptibility was dominant over resistance.

Sangwan and Lodhi (1998) investigated inheritance of flower colour and pod colour in cowpea (*Vigna unguiculata*) followed a qualitative pattern. Purple flower colour is dominant over white flower colour, whereas black pod colour is partially dominant over white pod colour. A segregation ratio of 3 purple:1 white flowers in F_2 generations of two crosses indicated that white flower colour is controlled by a single recessive gene. Segregation ratio of F_2, 1 white:2 light black:1 black indicated that black pod colour is partially dominant over white pod colour and is governed by one gene. These results were further confirmed by backcross generations. White flower and pod colour are controlled by single recessive genes on separate chromosome. Sirohi *et al.* (1998) studied inheritance of the hairy character on pods in the F_1, F_2 and back cross generations of two crosses of blackgram (*Vigna mungo*). Non-hairy character of pods showed monofactorial recessive inheritance.

Venugopal (1998) studied inheritance of unripe pod colour, pod orientation, pigmentation on tip and surface of the pod individually and in combination, colour and pattern of pigmentation of the pod in three cowpea crosses. F_1 and F_2 generation studies indicated light green pod colour to be dominant over green pod colour. Presence of pigmentation was found to be dominant over its absence in all the characters studied. One to five pairs of genes were involved in the inheritance of these characters. Kehinde and Ayo-Vaughan (1999) investigated genetic control of seed coat texture in the parental, F_1, F_2 and backcross populations of 4 crosses involving 7 accessions of cowpea (*Vigna* *unguiculata*). In two of the four crosses, inheritance of seed coat texture was found to be under monogenic control. In the other two crosses, the trait was found to be controlled by two genes with complementary effects, giving a segregation ratio of 9 smooth : 7 rough in the F_2 and 1 smooth : 3 rough in backcross generations.

Khattak *et al.* (1999) reported monogenic inheritance for seed coat colour. Black, black-spotted and dull-green seed coat colours were dominant over green, non-spotted (green) and shiny green colour, respectively. The inheritance of twining plant growth habit was found to be dominant over non-twining growth habit. The joint segregation studies of mungbean seed coat colour and plant growth habit in the F_2 and backcross generations revealed that these two traits are not linked. The absence of linkage between these two traits should make it possible to combine non-twining plant type and shiny green seed coat colour in the F_2 and subsequent generations.

Rao and Samy (1999) studied the inheritance of new plant types in blackgram - main stem bearing and compact bearing (sympodial bearing) in F_1 and F_2 generations. The inheritance of new plant types revealed that the main stem bearing habit was under the control of single dominant gene which is incomplete in expression (1:2:1). The compact bearing appears to be governed by duplicate recessive gene action (15:1) while the role of polygenes and modifiers could not be however, ruled out. Introducing genes for two new bearing types into existing cultivars will lead to increase in total pod number and enhance harvest index without reducing the biological yield.

Ghafoor *et al.* (2003) studied inheritance of qualitative characters in eleven blackgram genotypes of diverse origin. They observed that all the four traits (pubescence, seed coat colour, presence of spot on the seed and pod colour) revealed monogenic inheritance, (3:1) ratio. Hairiness was dominant over non-hairiness; brown seed coat colour dominant over green seed coat colour. Presence of spots on seed coat was dominant to absence of spots and black pods were dominant over brown pods. Seven hybrids revealed strong linkage between spots on seed coat and pod colour in the material studied.

2.3 Heterosis Study

Arora and Pandya (1987) investigated heterosis in 19 chickpea crosses and observed significant and positive heterosis over better parent for yield. They also suggested that the use of crosses involving genetically diverse parents with higher *per se* performance for exploitation through appropriate breeding methods for developing high yielding, pure line varieties in this crop.

Malik *et al.* (1987) studied heterosis over mid and better parents of 15 F_1 hybrids involving six groundnut varieties of diverse origin for seed yield and its component in groundnut. They observed positive heterosis over mid parents in many crosses and over better parents in several crosses for all the characters studied. Shinde & Deshmukh (1989) investigated heterosis in 5 hybrids derived from 4 diverse parents in urdbean. Maximum beneficial heterosis over better parent was obtained for grain yield per plant followed by biological yield per plant, number of pods per plant, number of fruiting branches and plant spread per plant. Relatively lower amount of heterosis was obtained for harvest, days to flowering, plant height, days to maturity, 100 grain weight and number of seeds per pod, most of the hybrids gave negative heterosis for number of seeds per pod and 100 grain weight. They also concluded that crosses between late tall growing genotypes with higher biological yield and the early short statured genotypes with higher harvest index provide enough scope for the genetic improvement of urdbean for higher yield and desirable yield attributes like grain size.

Zubair *et al.* (1989) reported varying degrees of variance for 6 characters in 7 crosses of mungbean. They observed high heterotic effects in both generations and high heritability estimates along with high genetic advance for yield and yield components. They concluded that the simple selection should be followed carefully in large segregating populations to find out the transgressive segregants for effective mungbean improvement. Vikas *et al.* (1998) pointed out that there was greatest heterosis for seed yield per plant in most case of mungbean crosses. Hybrids showing heterosis for seed yield per plant were also heterotic for 100 seed weight, number of seeds per pod and number of clusters per plant. They indicated 9 parents that were expected to be most promising for exploitation of heterosis for yield and its components. Vikas and Singh (1998) indicated that heterosis for seed yield was associated with heterosis for number of pods per plant, number of seeds per pod, 100 seed weight and harvest index in both environments.

Ghafoor *et al.* (1990) investigated heterosis over mid and better parent in five *Vigna mungo* L. parents and find out heterosis for plant height, branches per plant, pods per plant and grain yield. They suggested that two cross combination which produced high heterotic effects for grain yield that may be utilized for developing high yielding mash cultivars. Pant and Bajpai (1991) crossed 3 testers and 15 lines to study heterosis in field pea. Heterosis over better parent and mid parent was studied for ten characters in a trial of 45 hybrids and 18 parents. Crosses with one parent showed marked heterosis for primary branches, pod length, number of seeds/pod, biological yield and grain yield. Twenty three crosses showed significant heterosis for yield over better parent.

Rao (1991) investigated heterosis and inbreeding depression in 4 crosses derived from 7 diverse parents in urdbean. He observed maximum heterosis over better parent for number of pods/plant, number of seed/plant, seed yield/plant, number of seeds/pod, plant spread and pod length. Most of the hybrids gave negative heterosis for days to flower, plant height, pod bearing length and 100 seed weight. The heterosis observed for seed yield was mainly attributed through major yield components viz., number of seeds/plant and number of pods/plant. He suggested that genetic diversity in parents appears to play an important role in manifestation of heterosis.

Naidu and Satyanrayana (1993) investigated heterosis in mungbean lines and results out that maximum heterosis were observed over mid and better parent for seed yield, branches and cluster per plant. They also found average heterosis for days to 50% flowering and maturity over mid and better parent was negative. Sawant *et al.* (1994) studied cowpea hybrids and their 10 parents of diverse origin to investigate heterosis for seed yield/plant and 11 components. Greatest positive heterosis over mid-parent was observed for seed yield/plant (140.5%), followed by inflorescences/plant (139.3%), pods/plant (132.5%), branches/plant (85.6%) and plant height (73.4%). A smaller trend over better parent was observed except for branches/plant and plant height. Average heterosis over MP and BP was greatest for seed yield/plant (74.5 and 56.2%) followed by pods/plant (63.3 and 52.8) and inflorescences/plant (56.4 and 46.1%).

Andhale *et al.* (1996) studied heterosis in 8 blackgram varieties and their 10 F_1 and 10 F_2 progenies. High heterosis for seed yield/plant was coupled with high heterosis for plant spread, number of primary branches, cluster/plan, pods/plant and seeds/pod. Only one hybrid showed highest heterosis for seed yield coupled with the strongest inbreeding depression. Jha *et al.* (1996) conducted experiment to study the magnitude and direction of heterosis. The study indicated the feasibility of recovering early maturing, high yielding cultivars, but with much effort and from a large number of crosses. Kamatar *et al.* (1996) gave information on heterosis that it is derived from the data on seed yield and 8 related traits in 66 hybrids and their 17 diverse parents. Maximum positive heterosis was observed for pod number (144.3%), followed by seed yield/plant (130.5%), total number of branches/plant (120.5%) and protein content (47.1%). Primary branches/plant, branches/plant and pods/plant are major contributors to seed yield.

Bhor *et al.* (1997) evaluated F_1, F_2 and parents of 14 crosses of cowpea lines for 5 yield-related characters. Hybrids exhibiting high heterosis also showed high inbreeding depression, indicating the importance of non-additive gene action. Heterosis can therefore only be exploited by isolating desired segregants in subsequent generations. Verulkar and Singh (1997) gave information on heterosis that was derived from data on 10 yield components in 4 *Cajanus cajan* cultivars and their F_1 hybrids. Only single cross gave the highest heterosis for yield (54.6%), followed by another one having yield heterosis 44.2%.

Patil *et al.* (1998) studied 3 desi (D) and 2 kabuli (K) cultivars of chickpea and the extent of heterosis and heterobeltiosis of progenies for grain yield and morphological characters was evaluated. Desi x kabuli crosses showed high mid-parent heterosis for seed yield, plant height, primary branches and first pod bearing node, whereas K x K cross showed higher mid-parent heterosis for plant spread and internodal distance. D x D crosses showed high mid-parent heterosis for secondary branches only D x D cross exhibited higher better parent heterosis in desirable direction for morphological traits and seed yield. Viswanatha *et al.* (1998) reported significant heterosis over mid and better parent was observed for most characters studied. Crosses showing high heterosis also exhibited high inbreeding depression, indicating predominance of non-additive gene action for most traits studied.

Aher and Dahat (1999) conducted study to find out heterosis in 11 characters in 10 hybrids of mungbean results from crossing of 8 parents indicated pronounced hybrid vigour for yield and most of the yield contributing characters. Heterosis for yield was generally accompanied by heterosis for yield components. Three hybrids were identified as promising for many desirable traits and they may be of much use in exploiting hybrid vigour and isolating desirable segregants from further generation in mungbean.

Santha and Veluswamy (1999) evaluated 40 hybrids and estimated 9 yield related traits in blackgram with their parents. The highest estimates of heterosis were observed for primary branches, cluster, pod and seed yield among the 9 characters studied. Savithramma and Latha (1999) conducted study to estimate heterosis using 45 hybrids produced by crossing 10 cowpea genotypes in a diallel fashion without reciprocals. The best hybrid combinations for pods/plant, seeds/pod, seed yield and 100 seed weight were obtained in seven cross combinations.

Vikas *et al.* (1999) studied some 45 mungbean hybrids derived from 15 lines and three testers for heterosis for earliness at four locations and find out that in general, most of the hybrids involving MUM2 as one parent were early flowering, early maturity, shorter and had more primary branches. Jahagirdar, 2001 reported heterosis for seed yield in top yielding crosses of mungbean. Among the components traits, branches/plant showed significant positive heterosis over mid and better parent in all the above five high yielding crosses, suggesting importance of this component for realizing heterotic response of seed yield.

MATERIALS AND METHODS

MATERIALS AND METHODS

Experiment I

3.1 Breeding Methods

3.1.1 Experiment Material

Selection of parents in any crop plant to improve its genetic architecture through hybridization is a prerequisite in any plant breeding programme to release a most suitable and stable variety to boost up the economic output of the crop. Legumes are very important crops of Pakistan and widely grown especially on the marginal lands for sustainable agriculture. The local germplasm land races are valuable source for agricultural prosperity due to wider adaptability, good quality and resistant to biotic and Abiotic stresses. To identify the most suitable breeding method or selection method in blackgram, six genetically different parental lines were selected in a comprehensive study conducted by Ghafoor *et al.* (2000) for hybridization. 6 x 6 diallel set were attempted to establish F_1 hybrid seed during spring 1997 at pulses programme, National Agricultural Research Center, Islamabad (33.40° N and 73.07° E), Pakistan.

The characteristics of parental lines used in the present study were; i) NARC Mash 1, a released variety of NARC, is non-hairy, medium to bold seeded, spreading type, late maturing, and high yielding; ii) NARC Mash 3, also a released variety of NARC with hairy plant and pods, medium seed size, semi erect, early maturing and high yielding; iii) 9012 is an advance genotype having light hairy characteristics, bold seeded, semi spreading, medium maturing, high yielding and resistant to yellow mosaic virus; iv) 9020 is also an advance cultivar with light hairy, long pods, bold seeded, late maturing, high yielding characteristics and also resistant to yellow mosaic virus disease; v) 9025 is light hairy, early maturing, small stature, small seeded and high yielding cultivar, while the sixth one 9026 is also hairy, early maturing, high yielding and resistant to yellow mosaic virus.

3.1.2 Experiment Procedure

Thirty cross combinations (Table 3.1.1) were used to study three breeding methods. These crosses were initially selected from a diallel study involving six different parents. After initial evaluation of these crosses in F_1 generation, were advance to F_2 generation to study the three breeding methods. While evaluating these thirty crosses in F_1 generations few reciprocal crosses were rejected due to their poor performance and presence of insignificant genetic variations.

Table 3.1.1: Cross combination studied from F_1 to F_4 generations used for three breeding methods.

S. No.	F_1 Generation	F_2 Generation	F_3 Generation	F_4 Generation
1	9012/9020	9012/9020	9012/9020	9012/9020
2	9012/9025	9012/9025	9012/9025	9012/9025
3	9012/9026			
4	9012/Mash 1			
5	9012/Mash 3	9012/Mash 3		
6	9020/9012	9020/9012	9020/9012	9020/9012
7	9020/9025	9020/9025		
8	9020/9026	9020/9026		
9	9020/Mash 1	9020/Mash 1	9020/Mash 1	9020/Mash 1
10	9020/Mash 3	9020/Mash 3	9020/Mash 3	9020/Mash 3
11	9025/9012	9025/9012		
12	9025/9020	9025/9020		
13	9025/9026	9025/9026	9025/9026	9025 x 9026
14	9025/Mash 1	9025/Mash 1	9025/Mash 1	9025 x Mash 1
15	9025/Mash 3	9025/Mash 3		
16	9026/9012	9026/9012		
17	9026/9020			
18	9026/9025	9026/9025		
19	9026/Mash 1			
20	9026/Mash 3	9026/Mash 3		
21	Mash 1/9012			
22	Mash 1/9020	Mash 1/9020	Mash 1/9020	Mash 1/9020
23	Mash 1/9025	Mash 1/9025		
24	Mash 1/9026	Mash 1/9026	Mash 1/9026	Mash 1/9026
25	Mash 1/Mash 3	Mash 1/Mash 3		
26	Mash 3/9012	Mash 3/9012		
27	Mash 3/9020	Mash 3/9020		
28	Mash 3/9025			
29	Mash 3/9026	Mash 3/9026	Mash 3/9026	Mash 3/9026
30	Mash 3/Mash 1	Mash 3/Mash 1	Mash 3/Mash 1	Mash 3/Mash 1

During evaluation in F_2 generation few more crosses were dropped due to their poor performance, for F_3 generation as a final selection. Hence, F_3 generation carried forward to F_4 generation as such without further rejection in crosses' number. So, only eleven cross combination were left in F_3 and F_4 generations to compare the three breeding method for their effectiveness at two locations; i) National Agricultural Research Center (NARC), Islamabad (a research center of Pakistan Agricultural Research Council, Islamabad; ii) A private seed company farm "Seed and Services International" managed by Dr. Bashir Ahmad Malik (Ex-Coordinator Pulses/Director General, NARC, Islamabad) at Fateh Jang (FJ), District Attock. Many researchers (Haddad and Muehlbauer, 1981 in lentil; Pawar *et al.*, 1985 in wheat; Rajan and Peter, 1987 in tomato; Obisesan, 1987; Dahiya and Singh, 1986 in greengram; Dahiya *et al.*, 1987 in greengram; Bisen *et al.*, 1988 in chickpea and Fahim *et al.*, 1998 in rice) also compared different breeding methods in different segregating generations of various crops for their effectiveness and efficiency by following almost similar procedures.

In the same year, all F_1s of all crosses were sown in pots in under controlled green house conditions (30 – 35°C temperature) to get F_2 generations. The F_2 populations of all the crosses were sown at the same location but under field conditions at NARC during next kharif season (1998) and this F_2 population were divided into three groups to study the three breeding methods. Four meter row length, with plant to plant and row to row distance was maintained 10 and 30 cm respectively. Cultural practices recommended by Malik (1994) were followed to raise the experiment from F_1 to F_4 generations. The three sets were constituted viz., i) Single Plant Progenies (SPP), ii) Single Seed Descent (SSD) and iii) Bulk Population (BP) described by Grafius (1965); Brim (1966); Pawar *et al.* (1985); Haddad and Muehlbauer (1981) and Rehman and Bhall (1985). Single Plant Progenies (SPP) term is applicable to Pedigree Method (PM) in the present study where record of individual progenies for yield and its components we kept. Only selected plant progenies were carried forward to next generation for further selection to record the traits mentioned in Table 3.1.2. The detailed procedures of these breeding methods are described as under.

i) **Single Plant Progenies (SPP):** Twenty best single healthy plants were selected and properly labeled from each cross in F_2 generation of space plant population at their maturity. Each plant was properly labeled and was enveloped for data collection. The seeds of each single plant selected in F_2 generation, were kept separately to raise the next generation. In F_3 generation, the performance of these single selected plants was judged independently within and among the crosses. The same procedures were followed in F_4 generation of single plant progenies (SPP) for the character studied.

ii) **Single Seed Descent (SSD):** Single seed descent is the method least influenced by natural selection. From each plant of all cross combinations single pod was picked to get two seed for the raising the next generation from F_2 to F_3 and from F_3 to F_4 generation (Empig and Fehr 1971; Tee & Qualset, 1975; Martin *et al.*, 1978; Haddad and Muehlbauer, 1981; Dahiya and Singh 1985; Pawar *et al.*, 1985; and Dahiya, *et al.*, 1986). In F_4 generation the required data of desired traits mentioned in Table 3.1.2 were recorded to compare the three breeding methods.

iii) **Bulk Population (BP):** Plants of F_2 population of all cross combinations were harvested at maturity and their seeds were bulked separately but crosswise to grow F_3 and F_4 generations to practice the bulk population breeding method as described by Allard (1960); Luedders *et al.* (1973) and Haddad and Muehlbauer, 1981. The same procedure was followed in F_3 generation to grow F_4 generation. However, the over all population of all crosses reduced and consequently the plant population in F_3 and F_4 declined step by step. The best sixty plants were visually selected for data recording from each cross to study the Bulk breeding method in F_4 generation.

Table 3.1.2: Traits measured from F_1 to F_4 spaced plants generation with their parents.

S. No	Traits	Units	Abbreviation
1	Plant height	cm $plant^{-1}$ (from ground level to tip of mature plant)	PH
2	Branches per plant	Number of branches $plant^{-1}$	BP
3	Pods per plant	Number of pods $plant^{-1}$	PP
4	Pod length	5 pods length $plant^{-1}$	PL
5	Pod seeds	5 pods seeds $plant^{-1}$	PS
6	100 seed weight	g $plant^{-1}$	100SW
7	Biological yield	g $plant^{-1}$	BY
8	Grain yield	g $plant^{-1}$	GY
9	Harvest index	Biological yield $plant^{-1}$/Grain yield $plant^{-1}$ x 100 $plant^{-1}$	HI

3.1.3 Statistical Analysis

Frequency distribution

Frequencies were calculated within each breeding methods for all the traits recorded at 2 locations. This information was presented in the graphic form representing range, mean ($\overline{X}$), standard deviation (SD), mid parent (MP) value, frequencies and parental values (P1 & P2) for different breeding methods.

Analysis for harvest index

Harvest index is a key factor for yield improvement. So it was analysed for grain yield according to the range (class interval) as described in graphs to describe it in a meaningful manner. So the mean and standard deviation within the specified range was calculated for grain yield in all the three breeding methods over both the locations with the help of Microsoft Excel.

Correlation analysis

Simple correlation analysis of grain yield with other traits was computed to test the significance with the help of Microsoft Excel data analysis package. This includes all F_4 data of eleven crosses at both the locations for all the three methods.

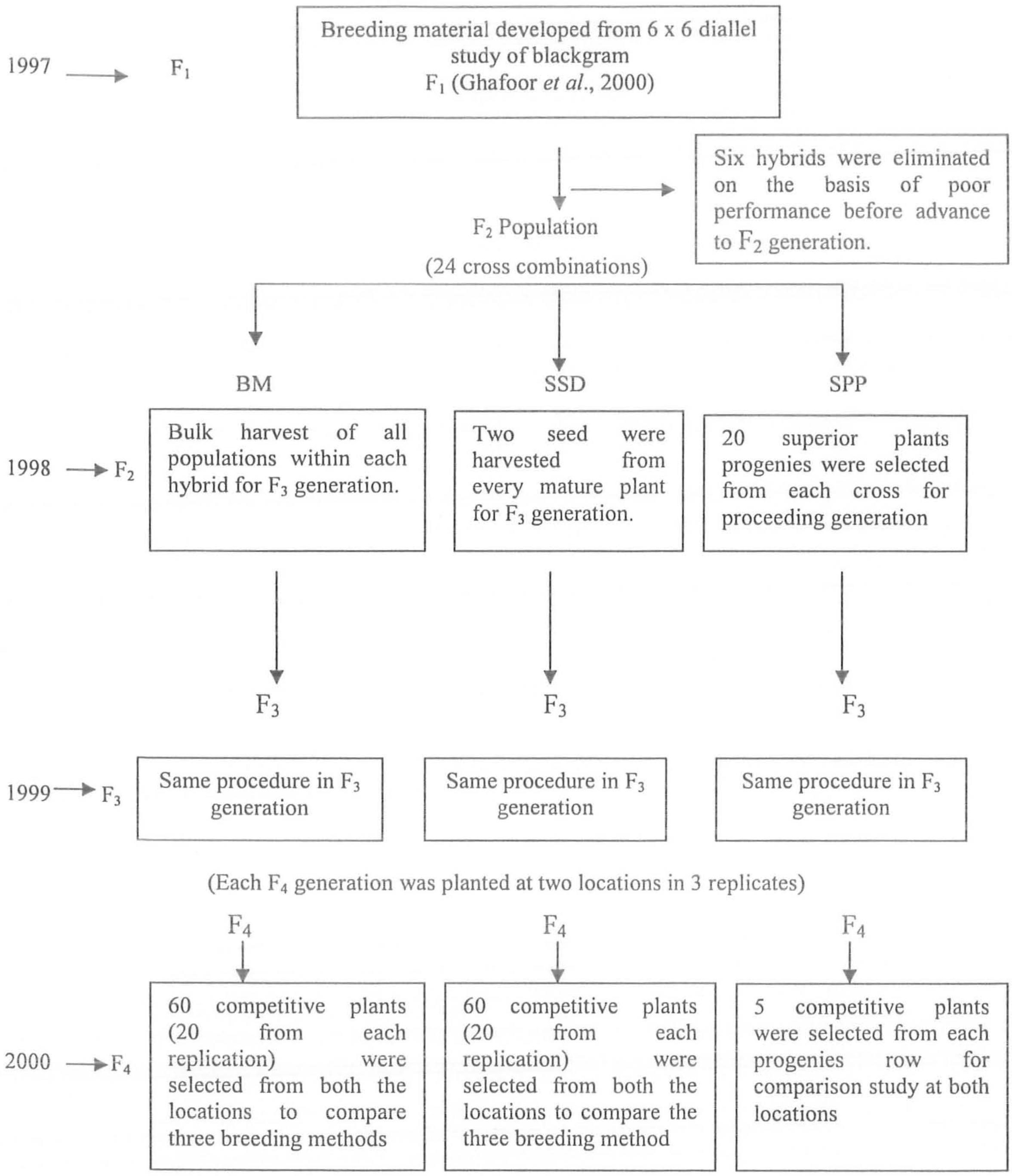
Number of plant percentage superior over mid parent value

Superior plant progenies percentage over mid parent in each cross for all the generation at both locations was identified for three breeding methods. Top three frequencies ranges were ranked as first, second and third on the basis of superiority over mid parent. The first ranked breeding method was given 3 score, second 2 score and third was marked as 1 score. These score numbers were added within each breeding method and then aggregated for all the hybrids.

Table 3.1.3 reveals the detail as sample case how these scores were calculated and aggregated to discuss the results for meaningful discussion. In the same way all the score allotted to all eleven hybrids in a breeding method for a character were also pooled over the location.

Table 3.1.3: Method developed for ranking and giving score for breeding methods and traits.

9025/Mash 1		PH		Br		Pods		PL		S/P		100SW		BY		GY		HI		Total Score
		Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	
NARC	**BM**	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	3	1	3
	SSD	0	0	2	2	3	1	3	1	0	0	0	0	0	0	2	2	0	0	6
	SPP	0	0	1	3	0	0	0	0	3	1	0	0	2	2	1	3	0	0	9
FJ	**BM**	3	1	0	0	0	0	0	0	1	3	0	0	0	0	0	0	3	1	5
	SSD	2	2	3	1	2	2	2	2	2	2	2	2	3	1	0	0	2	2	14
	SPP	1	3	0	0	1	3	1	3	0	0	1	3	1	3	1	3	0	0	18



Note: Out of 24 hybrids 11 were selected for F_3 generation and F_4 while remaining was planted under pulses program activity. Reciprocal crosses were eliminated in F_2 except two from all the 3 breeding methods.

Selection scheme of breeding methods followed from F_1 to F_4 generations in eleven crosses for 3 breeding methods in blackgram

Experiment II

3.2 Inheritance of Qualitative Characters

3.2.1 *Experiment Material*

The genotypes used for inheritance and linkage study included approved varieties (Mash 1 and Mash 3); advance breeding lines (45726) and pure-lines originally obtained from AVRDC (MM 33-40). The botanical descriptions of parents are given in Table 3.2.1. For present study a set of crosses were made during 1998 using the techniques reported by Ghafoor *et al.* (1999) at NARC Islamabad.

Table 3.2.1: Botanical descriptors of parents used in hybridization of blackgram.

Genotype	Source	Plant pubescence	Seed colour	Presence of spot on seed coat	Pod colour
Mash 1	Pakistan	Glabrous	Brown	Present	Black
Mash 3	Pakistan	Pubescent	Brown	Present	Black
MM 33-40	AVRDC	Pubescent	Green	Absent	Brown
45726	Pakistan	Pubescent	Brown	Present	Black

3.2.2 Experiment Procedure

The seeds obtained from three crosses (Mash 1/MM33-40, Mash 3/Mash 1 and 45726/MM33-40) were divided equally into two parts. Hybrid seeds were planted under field conditions at National Agricultural Research Center (NARC), Islamabad along with their parents for next year sowing (summer season) to raise F_1 population. The remaining hybrid seeds were preserved in the gene bank of Plant Genetic Resources Program, NARC for next year sowing. During summer 2000, the remaining hybrid seeds were planted along with the harvested seed from F_1 populations with parents. So in this way we have F_1 and F_2 generations with their parents at the same time in field conditions for simultaneous study. Plants were allowed to grow in an insect pest and weed free natural field conditions at 30 – 42 °C. Novacran 40 was applied @ 625 – 1250 ml/ha to protect the crop against MYMV. Data for plant pubescence was recorded at the 50% flowering stage. The spots on seed coat and pod colour were recorded after harvesting individual plants at maturity.

3.2.3 Statistical analysis

Data thus recorded were analysed with the help of chi-square (χ^2) most commonly used to test hypothesis concerning the frequency distribution of one or more populations. In this study, we used χ^2 for a fixed ratio hypothesis using data from F_2 segregating population of each cross as described by Gomez and Gomez (1984).

The linkage analysis among genetic markers in F_2 generation were investigated in three hybrids (Mash 1/MM33-40, Mash 1/45702 and 45726/MM33-40) for using the computer programme "LINKAGE 1" of Suiter *et al.* (1983).

Experiment III

3.3 Heterosis Study

3.3.1 Experiment Material

Six genotypes viz., Mash 1, Mash 3, 9012, 9020, 9025 and 9026 were selected from diverse groups based on evaluation under field condition from 1992 to 1994 and crossed under green house conditions during spring seasons (March to June) of 1994 to 1996 (Ghafoor *et al.*, 1999) at National Agricultural Research Center, Islamabad. Segregating generations (F_1 to F_4) were planted from years 1997, 1998, 1999 and 2000 along with their parents during kharif season under field conditions.

3.3.2 Experiment Procedure

The experiments were planted in a randomized complete block design (RCBD) with three replicates at the experimental field of National Agricultural Research Centre, Islamabad, Pakistan. Two rows of F_1 with parents were sown keeping 35 and 10 cm spacing between and within the rows, respectively. For other generations (F_2, F_3 & F_4) ten to fifteen rows were planted with same plant and row spacing. All other agronomic practices were adopted as recommended by Malik, 1994. Pesticides (Novacran 40 @ 625–1250 ml/ha) were sprayed to protect the crop from any infestation of insect pests especially white fly (*Bemisia tabaci* Genn.), a vector for Mungbean Yellow Mosaic Virus (MYMV). The data recorded on plant height (cm), number of branches plant^{-1}, number of pods plant^{-1}, 5 pod length (cm) plant^{-1}, seeds pod^{-5}, biological yield plant^{-1} (g) and grain yield plant^{-1} (g) on ten plants sampled at random within each hybrid and parents whereas, 30 plants in F_2 onward generations were sampled for data recording within each replication. Seed weight was recorded after counting 100 seeds in grams and harvest index calculated as a ratio between grain yield and biological yield that is expressed in terms of percentage. The other traits were measured as described in Table 3.1.2.

3.3.3 Statistical Analysis

Hybrid vigour was calculated as % decrease or increase in any trait over mid parents and better parents (Heterobeltiosis, word coined by Fonseca (1965) and then average of both heterotic values were calculated over the generations to minimize error. High mean values and maximum heterosis over mid and better parents in each cross of every trait were picked up to calculate scores for each hybrid. Three top ranked values were taken accordingly, aggregated and termed as scores. Genetic diversity was estimated through principal component analysis with the help of computer software "SPSS" for Windows.

RESULTS

RESULTS

Experiment I

4.1 Breeding Methodology

The analysis of variance of 11 crosses significantly differed for all the three breeding methods, varieties, locations and their interaction in F_4 generation, except pods length which was insignificant for locations (Table 4.1.1). Similarly, the analysis of variance for generations (F_1 – F_4), hybrids and generation for SPP breeding method significantly differed for all the characters except branches plant^{-1} in hybrid where it was insignificant. Insignificant replications indicated low influence of micro-environmental effects in the experiment (Table 4.1.2).

4.1.1 Plant Height

Plant height is one of the most important yield indicators in blackgram. It is significant for improving plant type. Medium height coupled with high numbers of pods and branches is desirable traits for improving yield potential in blackgram. High mean values were observed in all the three breeding methods at NARC as compared to Fateh Jang (FJ) location in hybrid 9025/Mash 1 (Fig. 4.1.1a and b). It also gave transgressive segregation toward lower side of mid parent at both the locations. The hybrid evaluated at FJ produced no plant with >50 cm plant height in all the three methods. Most of the plants were closer to parental value. The material evaluated at NARC gave normal distribution in all the three methods whereas, at FJ, only SPP gave normal distribution. Maximum frequency (84%) was achieved in SPP at NARC in F_3 where 42 plants out of 50 were better than mid parent (MP) value followed by 52.4% where 72 plants were superior over mid parent (MP) in SSP at FJ in F_4 generation (Table 4.1.3).

Negative transgressive segregation in Mash 3/Mash 1 was higher at FJ in all the breeding methods (Fig. 4.1.2a) whereas it was opposite at NARC (Fig. 4.1.2b). Normal distributions were observed in Bulk and SSD methods at FJ, while high negative transgressive segregants were achieved in SPP. At National Agricultural Research Center (NARC), SPP made a normal curve in this cross. Transgressive segregation was observed in all the breeding methods in this hybrid at NARC where high variances along with frequency towards both extremes were observed (Fig. 4.1.2b).

Table 4.1.1: Analysis of variance of F_4 Generation, 3 breeding methods, 2 locations and 11 crosses.

S.O.V	d.f	Plant height	Branches plant^{-1}	Pods plant^{-1}	5 Pods length plant^{-1}	5 Pods seed plant^{-1}	100 Seed weight plant^{-1}	Biological yield plant^{-1}	Grain yield plant^{-1}	Harvest index
Replication	2	11.68**	0.225	5.23	3.61*	2.59	0.00	1.39	0.17	30.15
Method	2	29.38*	3.59**	2.99.06**	10.61**	47.69**	0.03	108.96**	33.28**	214.01**
Variety	10	161.62**	1.18**	77.97**	5.58**	9.21**	0.89**	44.77**	7.91**	48.736**
Method x Variety	20	33.13**	0.80**	108.83**	5.87**	29.94**	0.12**	33.19**	7.36**	35.10**
Location	1	5080.75**	0.41**	142.02**	0.24	15.42**	10.28**	444.60**	54.88**	164.24**
Method x Location	2	897.35**	1.23*	119.74**	6.38**	13.03**	0.50**	153.54**	27.41**	30.40
Variety x Location	10	32.95**	0.90**	23.82*	2.26**	12.74**	0.32**	8.24**	1.03	43.69**
Method x Var x Loc	20	66.25**	0.31**	51.17**	2.58**	14.98**	0.19**	18.14**	3.81**	38.15**
Error	130	7.57	0.28	11.73	0.87	2.20	0.03	4.41	0.80	18.25
Replication		0.3386	0.0654	0.42	0.12	0.18	0.02	0.26	0.11	0.53
Method		0.3386	0.0654	0.42	0.12	0.18	0.02	0.26	0.11	0.53
Variety		0.6483	0.1252	0.81	0.22	0.35	0.04	0.50	0.21	1.01
Method x Variety		1.1229	0.2169	1.40	0.38	0.61	0.07	0.86	0.37	1.75
Location		0.2764	0.0534	0.34	0.10	0.15	0.02	0.21	0.09	0.43
Method x Location		0.4788	0.0925	0.60	1.16	0.26	0.03	0.37	0.16	0.75
Variety x Location		0.9168	0.1771	1.14	0.31	0.49	0.06	0.70	0.30	1.43
Method x Var x Loc		1.5880	0.3067	1.97	0.58	0.86	0.10	1.21	0.52	2.47
CV (%)		7.49	30.67	16.87	4.32	5.41	3.27	17.93	17.97	10.01

* and ** significant at 0.05 and 0.01 percent probability level, respectively. CV- Coefficient of Variability

Table 4.1.2: Analysis of variance from F_1 to F_4 Generations in Single Plant Progenies.

S.O.V	d.f	Plant height	Branches plant^{-1}	Pods plant^{-1}	5 Pods length plant^{-1}	5 Pods seed plant^{-1}	100 Seed weight plant^{-1}	Biological yield plant^{-1}	Grain yield plant^{-1}	Harvest index
Replication	2	8.56	56.47	50.04	0.95	1.32	0.02	111.51	6.301	0.29
Generation	3	4099.26**	9239.84**	64458.09**	46.83**	169.85**	1.94**	23914.92**	2936.36**	846.70**
Variety	10	359.71**	48.25	664.48	4.19**	16.06**	1.28**	650.18**	56.48**	55.41**
Generation x Variety	30	161.52**	60.84	856.58*	2.49	12.88**	0.26**	436.21**	37.66**	43.58**
Error		21.98	71.66	492.22	0.49	1.99	0.04	193.04	19.10	11.73
Replication		0.71	1.28	3.35	0.11	0.22	0.03	2.09	0.66	0.52
Generation		0.82	1.48	3.86	0.12	0.25	0.04	2.42	0.76	0.60
Variety		1.35	2.45	6.41	0.21	0.41	0.06	4.01	1.26	0.99
Generation x Variety		2.71	4.89	12.81	0.41	0.81	0.12	8.02	2.52	1.98
CV (%)		9.78	78.88	44.69	3.15	4.70	4.36	47.38	39.78	8.46

* and ** significant at 0.05 and 0.01 percent probability level, respectively.

CV- Coefficient of Variability

Note: **Br. M= Range, $\overline{X} \pm$ SD** and **legends pattern** shown in the box of first graph of a character (from next page to onward) will be considered the same for all graphs and character presenting the breeding methods in this chapter.

Plant height is very difficult to evaluate because it is much influenced by environmental fluctuations. Hence plant with high grain yield could be selected from this hybrid in F_4 or in later generations. High intermediate transgressive segregation was observed at NARC as compared to FJ location, where, range in parents was low. Ninety-percent plants (27 out of 30 plants) were found superior to MP in SPP breeding method in F_2 at NARC location. While 72% plants (36 out of 50 plants) were better in plant height over MP in F_3 at NARC. However, 63 plants (39.38%) were also superior to MP in SPP breeding method in F_4 at FJ location (Table 4.1.3).

In the hybrid Mash 3/9026, BM gave low segregants as compared to SSD and SPP, hence, less chance of selection is expected in this hybrid at FJ (Fig. 4.1.3a). Single Plant Progenies giving more plant height which revealed additive type of gene action at both the locations. Low to intermediate type of transgressive segregation was observed at this location and no plant with plant height >40cm was observed in BM and SSD. However, this hybrid gave better opportunity of plant selection for short stature cultivar. Bulk method produced more than 90% progenies with <MP value, whereas 20%progenies were <MP in SSD. The experiment conducted at NARC gave better results as compared to FJ. High mean values and desirable transgressive segregants in all the breeding methods indicated that selection of desired plant height could be possible in this cross (Fig. 4.1.3b). As one of the parent in this cross is approved variety with short duration, short stature and high yielding with good plant type having high yield potential was expected from this hybrid at both locations. While comparing the results of both locations, it was observed that at NARC higher range was observed in all the breeding methods as compared to FJ for selection of better plant biotype.

All the plant progenies were better in plant height to MP at NARC in F_2. This was followed by 47 plants out of 50 (94%) that were superior over MP in F_3 SPP at NARC. However, 41 plants were also superior to MP in F_4 at FJ in SSD breeding method (Table 4.1.3).

High mean values for all the breeding methods were observed in hybrid Mash 1/9026 at NARC as compared to FJ, indicating better scope of selection for desired plant progenies under better environment at NARC (Fig. 4.1.4a and b). High mean values and limited amount of intermediate transgressive segregation in all the breeding methods indicated that selection of desired plant could be easily practiced in combination with

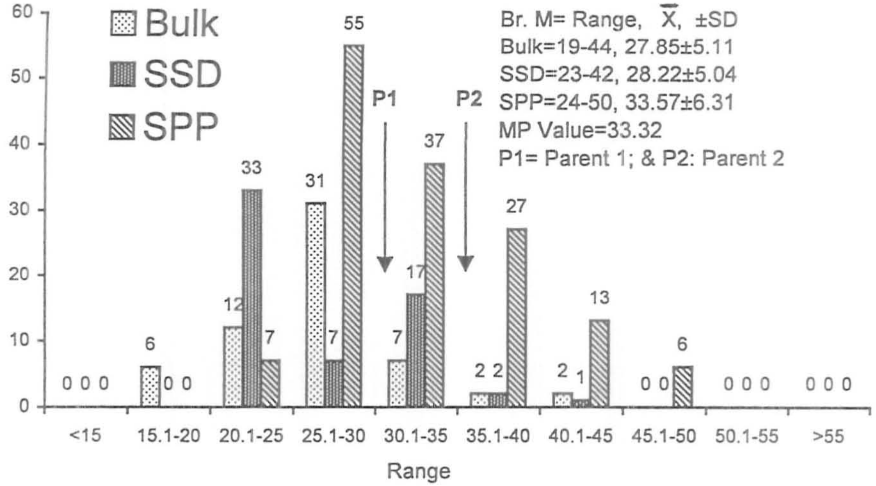


Fig. 4.1.1a. Comparison of three breeding methods for plant height plant^{-1} in 9025/Mash 1 of blackgram at FJ

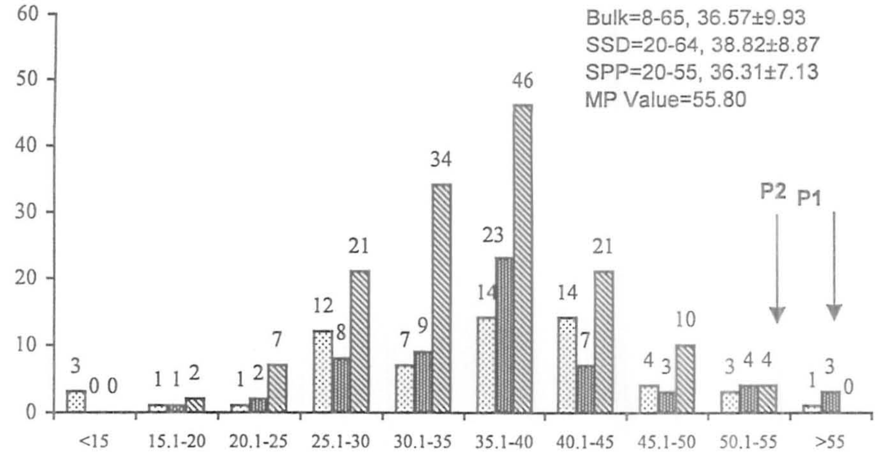


Fig. 4.1.1b. Comparison of three breeding methods for plant height plant^{-1} in 9025/Mash 1 of blackgram at NARC

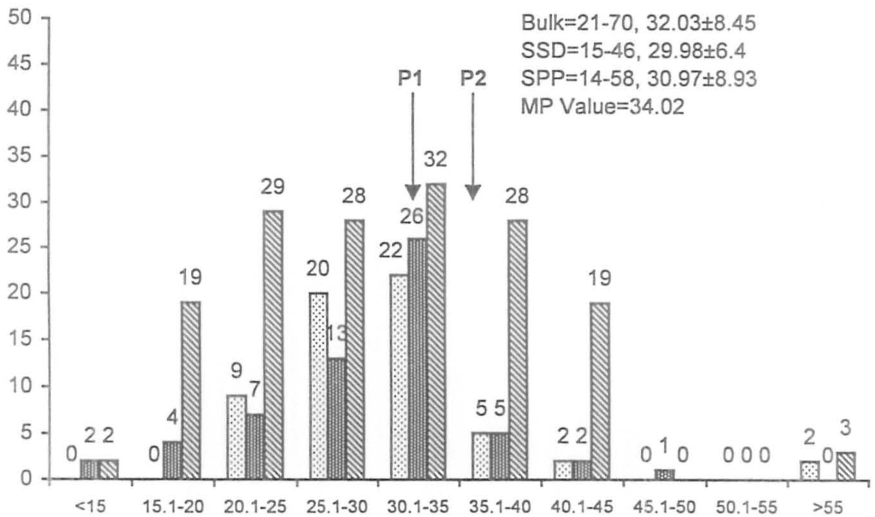


Fig. 4.1.2a. Comparison of three breeding methods for plant height plant^{-1} in Mash 3/Mash 1 of blackgram at FJ

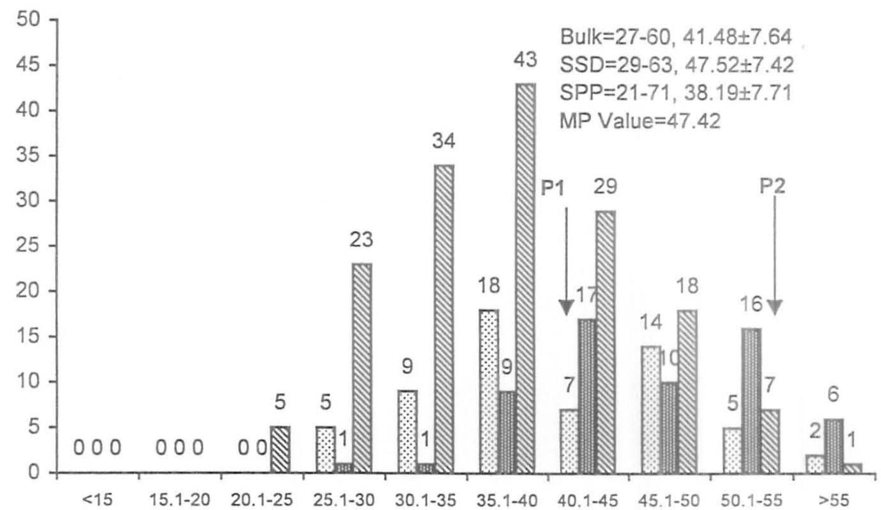


Fig. 4.1.2b. Comparison of three breeding methods for plant height plant^{-1} in Mash 3/Mash 1 of blackgram at NARC

desired traits at NARC as compared FJ. However, negative transgressive segregation was observed at NARC as compared to FJ. At FJ narrow range was observed while at NARC it was broad indicating high a range of plant biotypes. At FJ only two plants were observed with plant height >45cm where other methods did not give any tall plant. Single Plant Progenies produced similar pattern of segregation at both the location, although it gave slightly higher plant height at NARC.

All the plants were superior in this trait to MP in F_2 at NARC (Table 4.1.3). It was followed by F_3 generation where 98% plants were better in their plant height to MP at NARC in SPP. Moreover, the same breeding method produced 40.95% (43 plants out of 105) better plant to MP at FJ in F_4. It was clear that superior plants' ratio over the mid parent was higher in early generation as compared to later.

Fig. 4.1.5a indicated negative transgressive segregation in all the three breeding method in hybrid 9012/9025 at FJ. Although there was no intermediate type of transgressive segregation at FJ, but high frequency of plant progenies were observed in all the breeding methods closer to mid parent indicating scope of selection for shorter plants. High negative transgressive segregations were observed in BM where only few plants were on positive side of mid parent. At FJ there was a limitation of selection of taller plants in all the breeding method.

The result obtained in the same hybrid tested at NARC, revealed that high mean values were observed at this location as compared to FJ in all the breeding methods (Fig. 4.1.5b). The range of parents was higher at NARC that could be due to better moisture regime at this location. There were medium types of plants in all the breeding methods than FJ where narrow range was observed in this cross. At NARC negative transgressive segregation was observed in all the three methods. While comparing both the location for three breeding method, it was clear that high frequency at NARC in all the breeding method indicated scope of selection for medium plant height ranging from 30 to 45cm.

This hybrid produced 32 plants out of 50 (64%) in SPP, which were superior to MP for plant height in F_3 at NARC. In F_4, at FJ 44 plants (44%) were observed better to MP for this trait (Table 4.1.3). However, 26 plants were also better in plant height in F_4 at FJ in SSD breeding method. As tall plant type is not a much desirable trait in blackgram, hence medium plants with high yield potential are suggested to select from F_4 at both the locations.

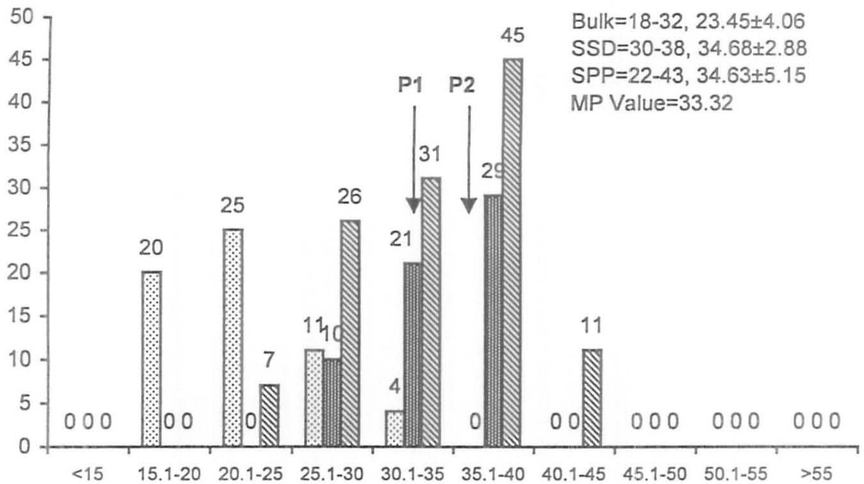


Fig. 4.1.3a. Comparison of three breeding methods for plant height plant^{-1} in Mash 3/9026 of blackgram at FJ

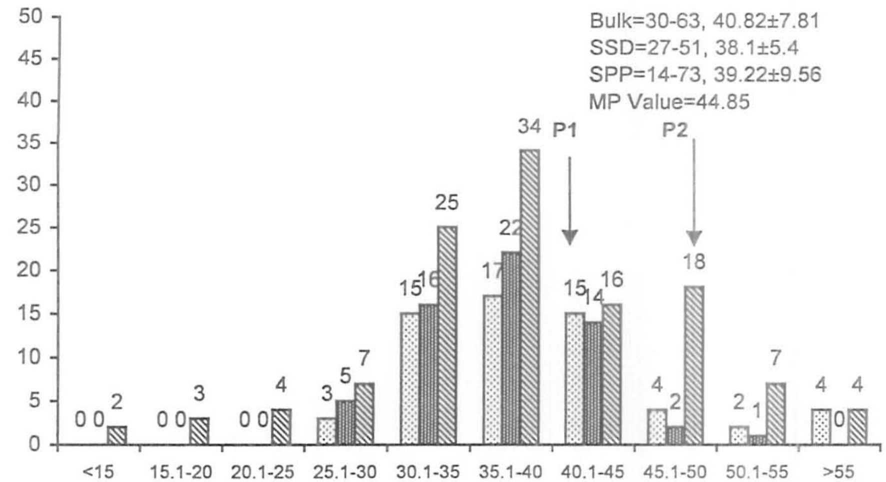


Fig. 4.1.3b. Comparison of three breeding methods for plant height plant^{-1} in Mash 3/9026 of blackgram at NARC

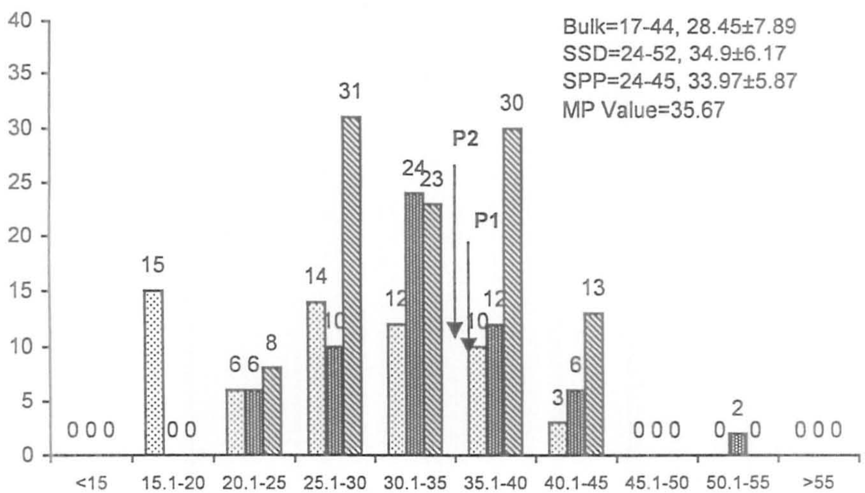


Fig. 4.1.4a. Comparison of three breeding methods for plant height plant^{-1} in Mash 1/9026 of blackgram at FJ

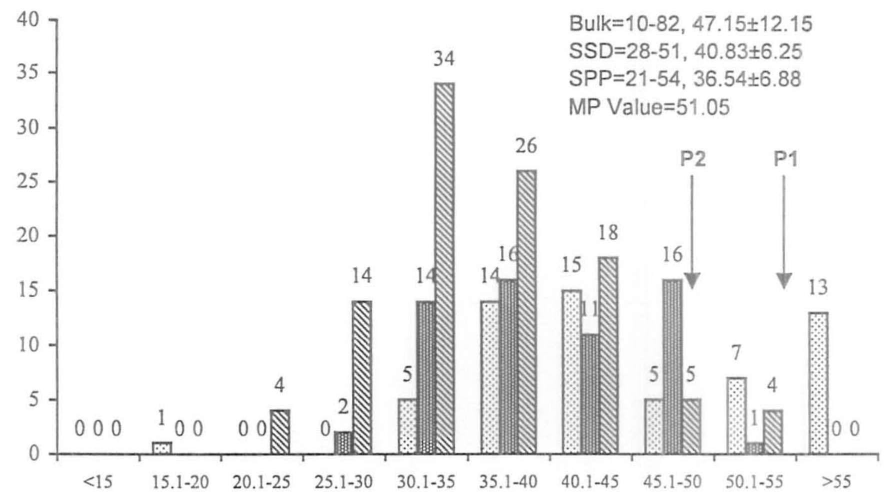


Fig. 4.1.4b. Comparison of three breeding methods for plant height plant^{-1} in Mash 1/9026 of blackgram at NARC

The hybrid 9020/Mash 3 tested at FJ revealed low mean values for BM and SSD while high in SPP when compared with NARC results (Fig. 4.1.6a). The parent 9020, used in this cross is an erect and responsive to high moisture, hence this hybrid did not exhibit desirable segregation, especially for BM and SPP at Fateh Jang. Negative and positive transgressive segregation was observed in BM and SPP, respectively. Results showed that taller plants could be selected from SPP while shorter to medium genotypes could be selected in BM and SSD.

The results obtained at NARC were almost opposite to the results observed at FJ (Fig. 4.1.6b). High mean values were observed in BM and SSD while low in SPP. More frequency of intermediate plants was observed at this location in all the breeding methods to select desirable plants for plant height. While comparing the result at both locations it was obvious that results of NARC were comparatively better than the result at FJ.

All the plants were superior to MP in F_4 Single Plant Progenies at NARC and it was followed by 90% plants which were better in their plant height to MP in F_4 at FJ in the same breeding method. Single Seed Descent also produced 85% (51 plants) better plants in F_4 at NARC (Table 4.1.3).

Low mean values coupled with narrow range were observed in the cross, 9020/Mash 1 in F_4 at FJ as compared to NARC, where high mean values along with intermediate type of transgressive segregation were observed for all the three breeding methods (Fig. 4.1.7a and b). At Fateh Jang, BM segregated toward negative side of the mid parent except two plants. However, high genetic variance toward positive direction was observed in SPP in this cross at both the locations. In general a narrow range with varying class intervals was observed in this cross at FJ that indicated the influence of selection procedure in fixing genes for plant height.

While comparing this hybrid with their mid parent value it was observed that 100 % plants were better than MP in F_4, in Single Plant Progenies at FJ and it was followed by NARC where 90.9% plants were better in F_4 in same breeding method (Table 4.1.3). Single Seed Descent also played an important role in selection of desirable plant biotype where 49 plants were better to mid parent at FJ in F_4.

The hybrid Mash 1/9020 tested at NARC revealed high mean value coupled with broad intermediate transgressive segregants as compared to FJ in F_4 in all the breeding methods, where low mean value and narrow range was observed (Fig. 4.1.8a and b). At

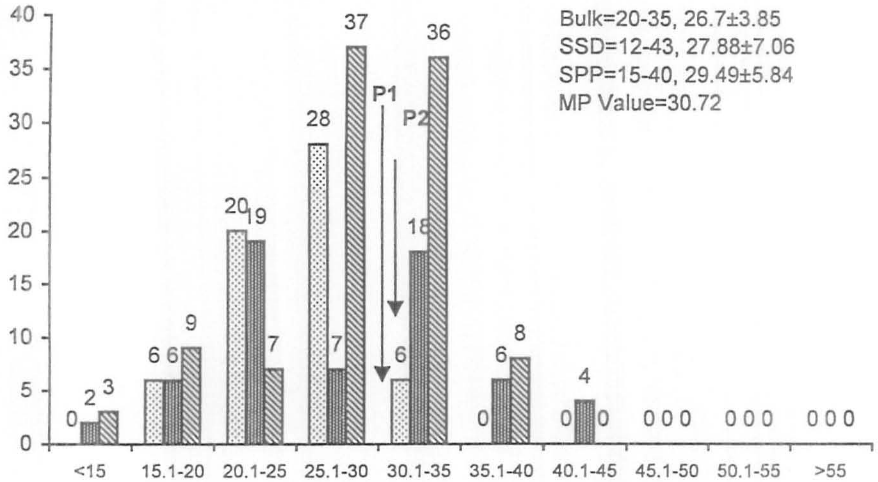


Fig. 4.1.5a. Comparison of three breeding methods for plant height plant^{-1} in 9012/9025 of blackgram at FJ

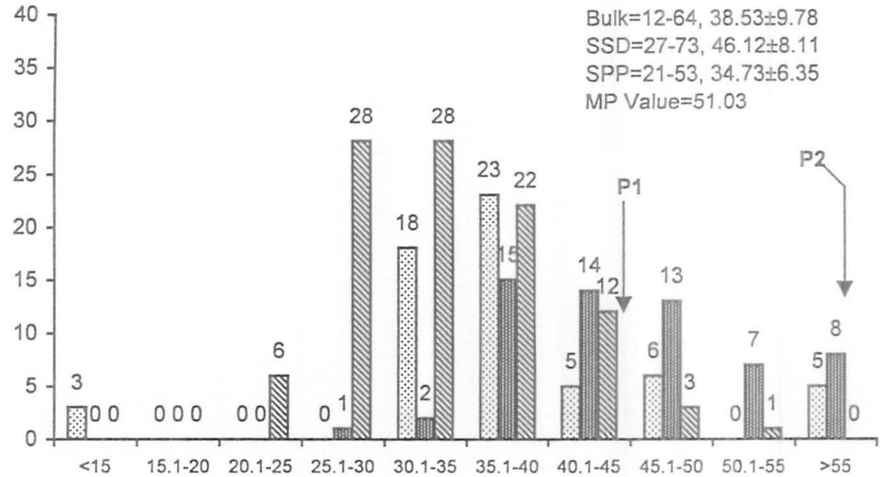


Fig. 4.1.5b. Comparison of three breeding methods for plant height plant^{-1} in 9012/9025 of blackgram at NARC

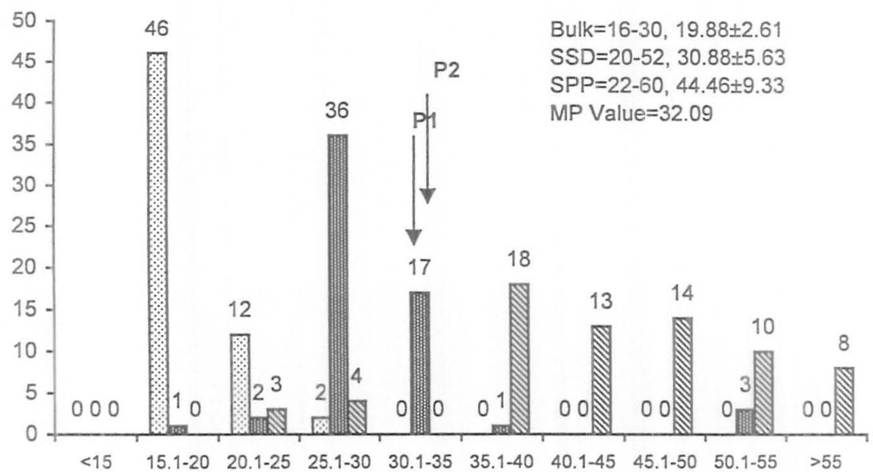


Fig. 4.1.6a. Comparison of three breeding methods for plant height plant^{-1} in 9020/Mash 3 of blackgram at FJ

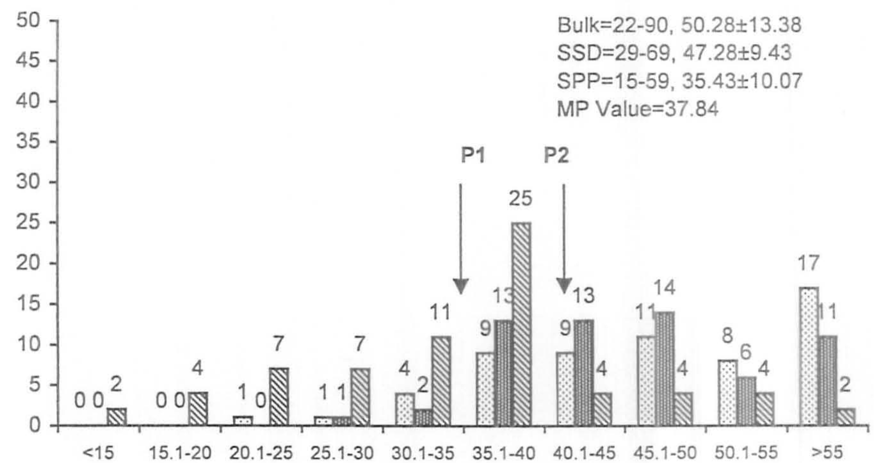


Fig. 4.1.6b. Comparison of three breeding methods for plant height plant^{-1} in 9020/Mash 3 of blackgram at NARC

FJ none of breeding methods produced any plant having > 40cm plant height while it was reverse at NARC where SSD produced only three plants with minimum plant height <30cm per plant. Single Plant Progenies produced maximum plant frequency near mid parent providing an opportunity to select plants with desirable plant height.

All the plants were observed better in plant height in F_2 at NARC over MP, and F_3 produced 49 plants out of 50 (98%) which were better than MP (Table 4.1.3) in SPP breeding method. Bulk method produced 52 plants out of 60 (86.67%) over MP in F_4 at NARC. Single Plant Progenies produced 81.82% plants over MP in F_4 at NARC. The overall generations' wise result indicated that SPP and BM produced better plants for plant height.

High mean values with broad intermediate transgressive range were observed in BM and SSD breeding method for 9020/9012 at NARC (Fig. 4.1.9a). Narrow range at FJ, where all the three methods fall in the middle, whereas at NARC the range falls toward positive side (Fig. 4.19b). High ranges of transgressive segregation were revealed in SSD followed by BM at NARC. This was because both the parents were medium in plant height and responsive to better environments. All the plants identified were superior to MP in SPP at NARC in F_4, while 90% plants were also better in plant height to MP in single seed descent (Table 4.1.3). Forty two plants out of 50 were better in their desired trait at NARC in F_3 SPP.

High ranges of transgressive segregation in either side of MP were observed in all the breeding methods at NARC for the hybrid 9012/9020, while it was low at FJ with high frequency near MP (Fig. 4.1.10a and b). Better chance exists to select good plants at NARC in all the breeding methods as compared to FJ in this cross. Forty-six out of fifty five (83.64%) and 78.33% plants were superior in plant height over MP in SPP and SSD at NARC in F_4, respectively. Whereas, 78.18% plants were higher in plant height to MP in F_4 SPP at Fateh Jang (Table 4.1.3).

While comparing the results hybrid 9025/9026 obtained from both locations, it revealed that high mean values in BM and in SSD breeding methods were observed at NARC while at FJ it was observed in SPP (Fig. 4.1.11a and b). High ranges of transgressive segregation were observed in SPP at both the locations. However, 34 and 14 plants appeared near the MP. These plant progenies may be helpful in selecting

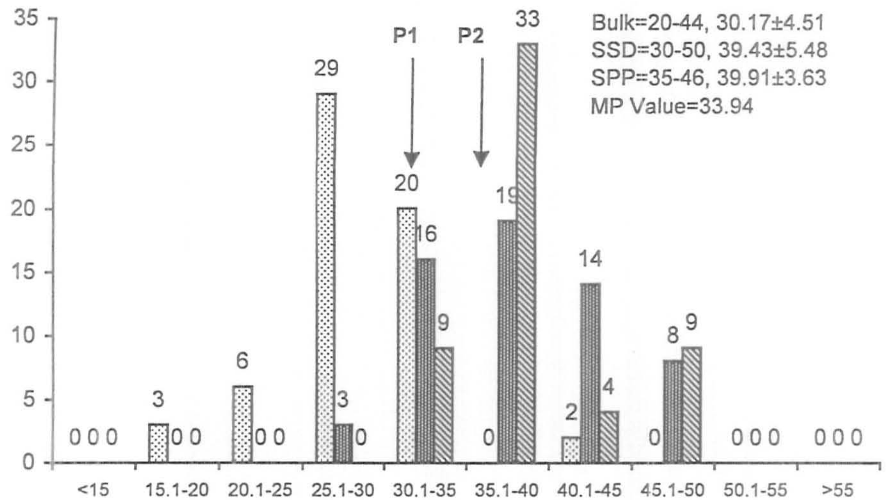


Fig. 4.1.7a. Comparison of three breeding methods for plant height plant^{-1} in 9020/Mash 1 of blackgram at FJ

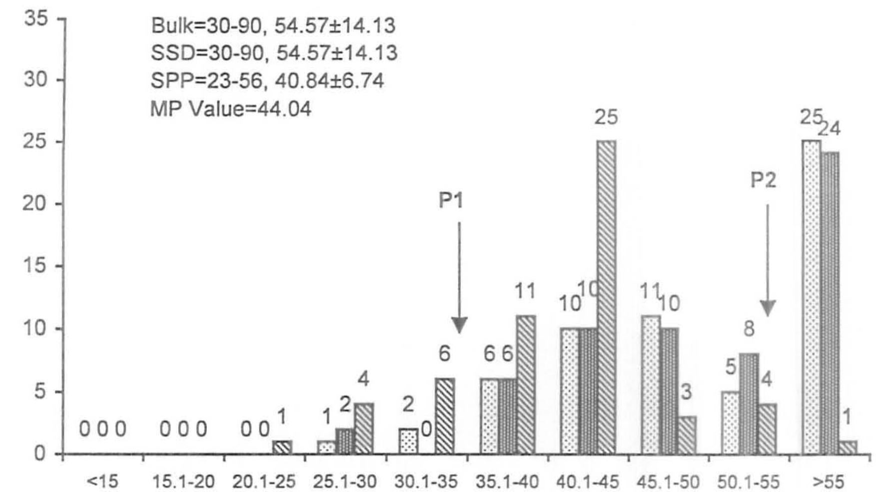


Fig. 4.1.7b. Comparison of three breeding methods for plant height plant^{-1} in 9020/Mash 1 of blackgram at NARC

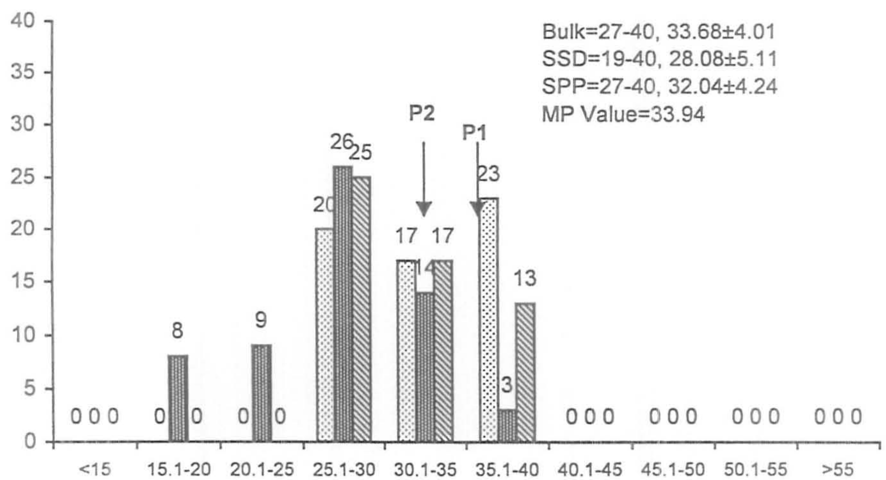


Fig. 4.1.8a. Comparison of three breeding methods for plant height plant^{-1} in Mash 1/9020 of blackgram at FJ

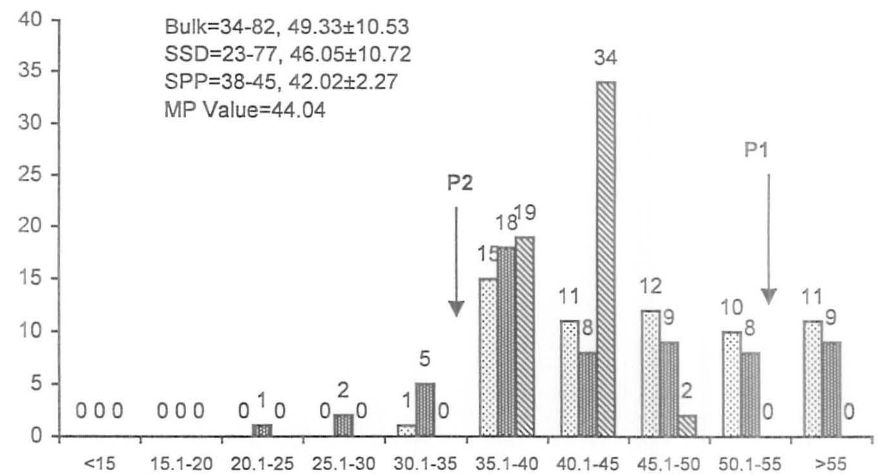


Fig. 4.1.8b. Comparison of three breeding methods for plant height plant^{-1} in Mash 1/9020 of blackgram at NARC

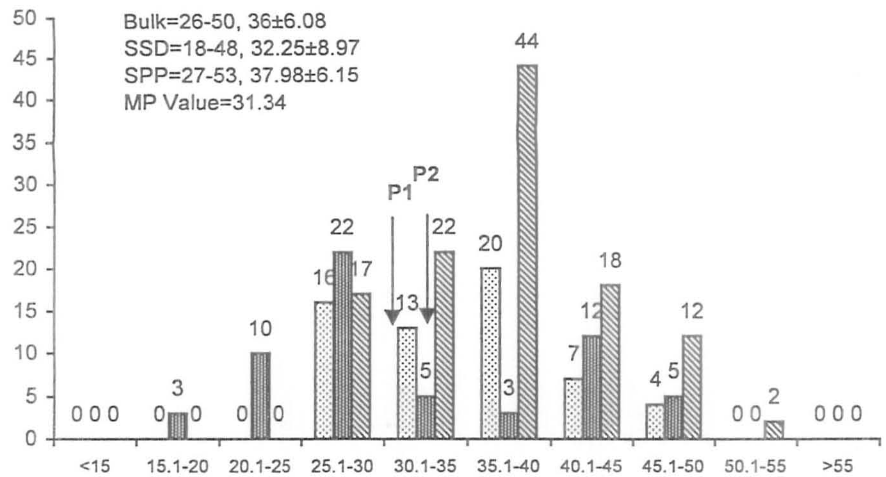


Fig. 4.1.9a. Comparison of three breeding methods for plant height plant^{-1} in 9020/9012 of blackgram at FJ

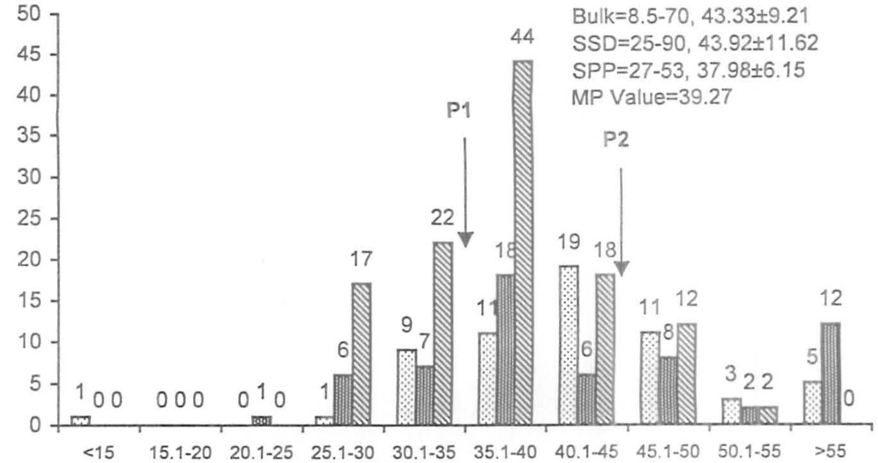


Fig. 4.1.9b. Comparison of three breeding methods for plant height plant^{-1} in 9020/9012 of blackgram at NARC

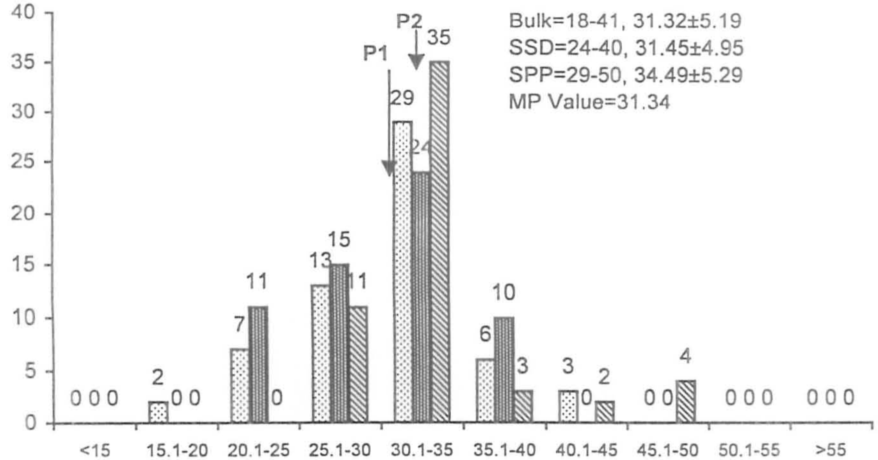


Fig. 4.1.10a. Comparison of three breeding methods for plant height plant^{-1} in 9012/9020 of blackgram at FJ

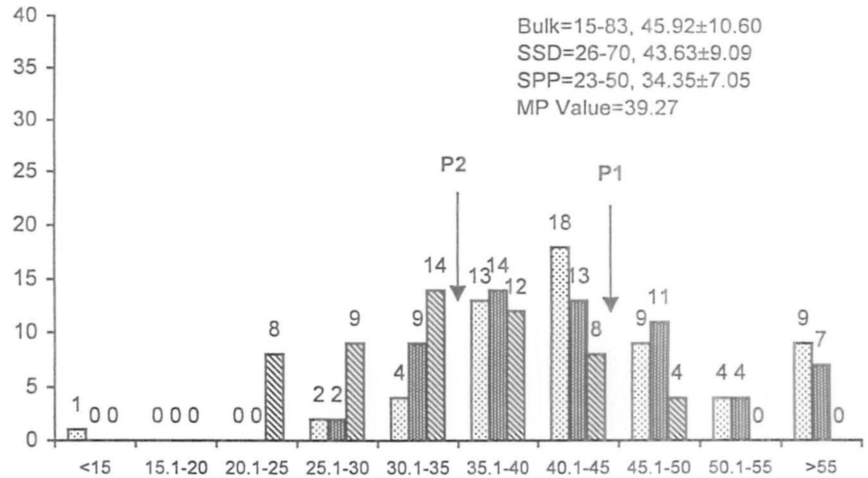


Fig. 4.1.10b. Comparison of three breeding methods for plant height plant^{-1} in 9012/9020 of blackgram at NARC

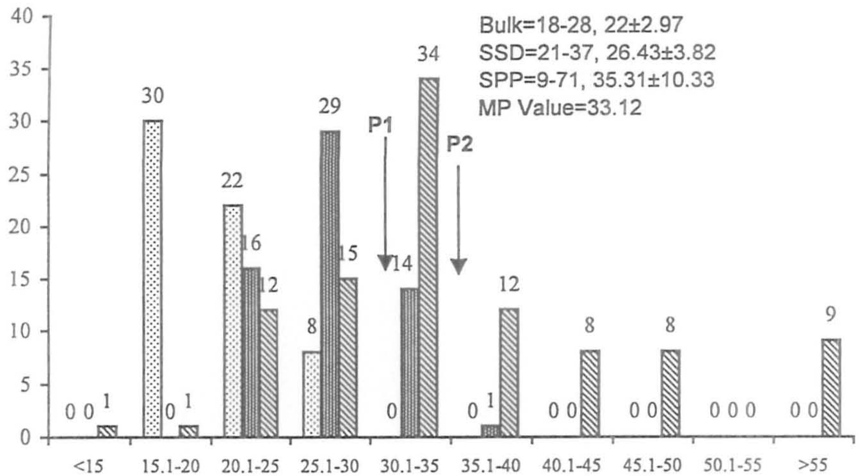


Fig. 4.1.11a. Comparison of three breeding methods for plant height plant-1 in 9025/9026 of blackgram at FJ

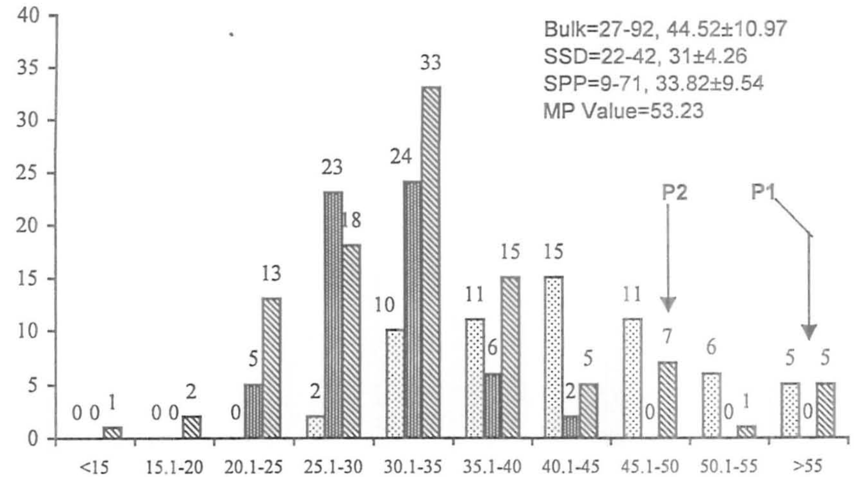


Fig. 4.1.11b. Comparison of three breeding methods for plant height plant-1 in 9025/9026 of blackgram at NARC

Table 4.1.3: Number of plants and their percentage over mid parent value in plant height plant^{-1} in 11 crosses at two locations.

Gen.	Location	Br. M.	M P Value	No. of sample collected	No. of plants over MP	%age over MP	M P Value	No. of sample collected	No. of plants over MP	%age over MP	M P Value	No. of sample collected	No. of plants over MP	%age over MP
			9025/Mash 1				**Mash 3/Mash 1**				**Mash 3/9026**			
F_2	NARC	SPP	56.60	30	12	40.00	48.75	30	27	90.00	36.65	30	30	100.00
F_3	NARC	SPP	38.70	50	42	84.00	34.15	50	36	72.00	36.50	50	47	94.00
F_4	NARC	SPP	55.80	145	0	0.00	47.42	160	57	35.63	44.85	120	26	21.67
F_4	FJ	SPP	33.32	145	76	52.41	34.02	160	63	39.38	33.82	120	71	59.17
F_4	FJ	BM	33.32	60	4	6.67	34.02	60	13	21.67	33.82	60	0	0.00
F_4	NARC	BM	55.80	60	1	1.67	47.42	60	15	25.00	44.85	60	16	26.67
F_4	FJ	SSD	33.32	60	15	25.00	34.02	60	11	18.33	33.82	60	41	68.33
F_4	NARC	SSD	55.80	60	0	0.00	47.42	60	19	31.67	44.85	60	17	28.33
			Mash 1/9026				**9012/9025**				**9020/Mash 3**			
F_2	NARC	SPP	53.00	30	30	100.0	61.95	30	0	0.00	51.75	30	24	80.00
F_3	NARC	SPP	35.40	50	49	98.00	39.00	50	32	64.00	36.25	50	39	78.00
F_4	NARC	SPP	51.05	105	0	0.00	51.03	100	7	7.00	37.84	70	70	100.00
F_4	FJ	SPP	35.67	105	43	40.95	30.72	100	44	44.00	32.09	70	63	90.00
F_4	FJ	BM	35.67	60	13	21.67	30.72	60	6	10.00	32.09	60	0	0.00
F_4	NARC	BM	51.05	60	3	5.00	51.03	60	2	3.33	37.84	60	38	63.33
F_4	FJ	SSD	35.67	60	20	33.33	30.72	60	26	43.33	32.09	60	11	18.33
F_4	NARC	SSD	51.05	60	7	11.67	51.03	60	7	11.67	37.84	60	51	85.00
			9020/Mash 1				**Mash 1/9020**				**9020/9012**			
F_2	NARC	SPP	68.10	30	12	40.00	68.10	30	30	100.0	73.45	30	3	10.00
F_3	NARC	SPP	35.60	50	38	76.00	35.60	50	49	98.00	35.90	50	42	84.00
F_4	NARC	SPP	44.04	55	50	90.91	44.04	55	45	81.82	39.27	115	115	100.00
F_4	FJ	SPP	33.94	55	55	100.0	33.94	55	19	34.55	31.34	115	93	80.87
F_4	FJ	BM	33.94	60	11	18.33	33.94	60	35	58.33	31.34	60	47	78.33
F_4	NARC	BM	44.04	60	36	60.00	44.04	52	60	86.67	39.27	60	46	76.67
F_4	FJ	SSD	33.94	60	49	81.67	33.94	60	9	15.00	31.34	60	25	41.67
F_4	NARC	SSD	44.04	60	35	58.33	44.04	60	31	51.67	39.27	60	54	90.00
			9012/9020				**9025/9026**							
F_2	NARC	SPP	73.45	30	6	20.00	44.50	30	27	90.00				
F_3	NARC	SPP	35.90	50	17	34.00	40.60	50	11	22.00				
F_4	NARC	SPP	39.27	55	46	83.64	53.23	100	0	0.00				
F_4	FJ	SPP	31.34	55	43	78.18	35.12	100	48	48.00				
F_4	FJ	BM	31.34	60	27	45.00	35.12	60	0	0.00				
F_4	NARC	BM	39.27	60	34	56.67	53.23	60	9	15.00				
F_4	FJ	SSD	31.34	60	34	56.67	35.12	60	10	16.67				
F_4	NARC	SSD	39.27	60	47	78.33	53.23	60	2	3.33				

desired plant biotype. In BM all the plant progenies were skewed negative side of the lower parent.

Twenty seven out of 30 plants (90%) were better in plant height to MP in F_2 at NARC in SPP. Forty eight plants out of hundred were found better to MP at FJ in SPP in F_4 (Table 4.1.3). In this cross it is suggested that selection of superior plants could be done in early generations, and enhanced separately in progeny rows to maintain their desired level of plant height.

4.1.2 Number of branches

Generally, number of branches plant^{-1} is positively correlated with grain yield thus more number of branches is supposed to be supportive to increase economic yield in blackgram. High mean values for branches plant^{-1} were observed in hybrid 9025/Mash 1 for all the breeding methods at NARC, whereas it was low at FJ (Fig. 4.1.12a and b). More transgressive segregation was observed in SPP at NARC as compared to FJ. While limited transgressive segregation towards positive magnitude was observed in other breeding methods at both the locations.

Single Plant Progenies produced 125 plants out of 145 (86.2%) higher for branches plant^{-1} than mid parent in F_4 at NARC. In same generation, 45 plants out of 60 (75%) showed superiority over MP in SSD at NARC, whereas 86 out of 145 plants were better in branches in SPP at FJ (Table 4.1.4). The results obtained in this hybrid at both the locations revealed that SPP and SSD breeding methods were better in selection of plants with higher number of branches plant^{-1}.

The hybrid, Mash 3/Mash 1 revealed high level of genetic variance coupled with transgressive segregation in SPP at both the locations for number of branches plant^{-1} (Fig. 4.1.13a and b). Normal frequency was observed in SPP at both the locations. High range coupled with low to medium variance was observed in BM toward positive direction at NARC and limited frequency of positive transgressiveness was observed in SSD at both the locations. High mean values were observed in all the breeding methods at NARC that supported the selection for more number of branches plant^{-1} at this location. Fifty-eight plants out of 60 (96.7%) were superior to mid parent in BM at NARC in F_4 and it was followed by 151 plants out of 160 (94.4%) in SPP at NARC. Moreover, SSD produced 90% better plants to MP in same generation at NARC (Table 4.1.4).

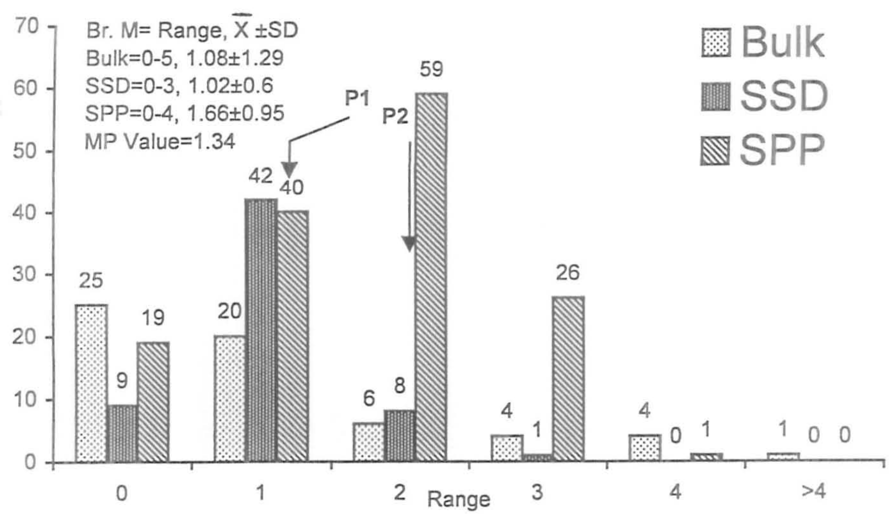


Fig. 4.1.12a. Comparison of three breeding methods for branches plant^{-1} in 9025/Mash 1 of blackgram at FJ

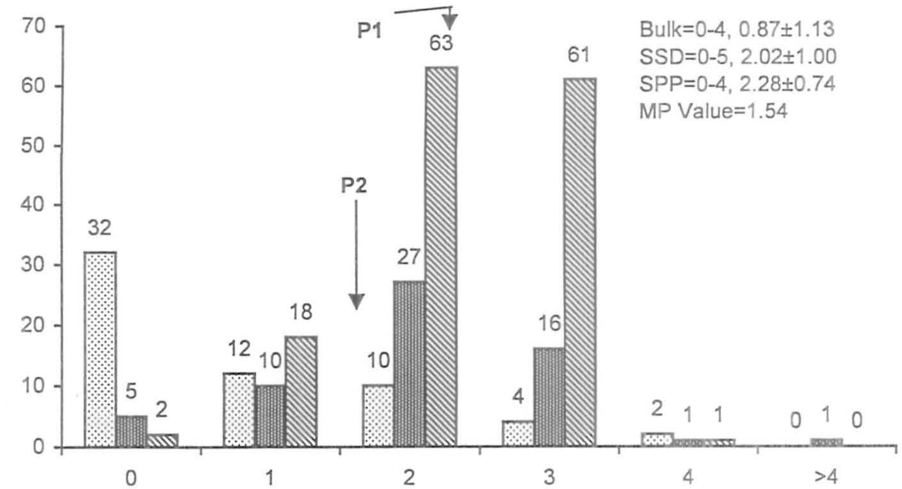


Fig. 4.1.12b. Comparison of three breeding methods for branches plant^{-1} in 9025/Mash 1 of blackgram at NARC

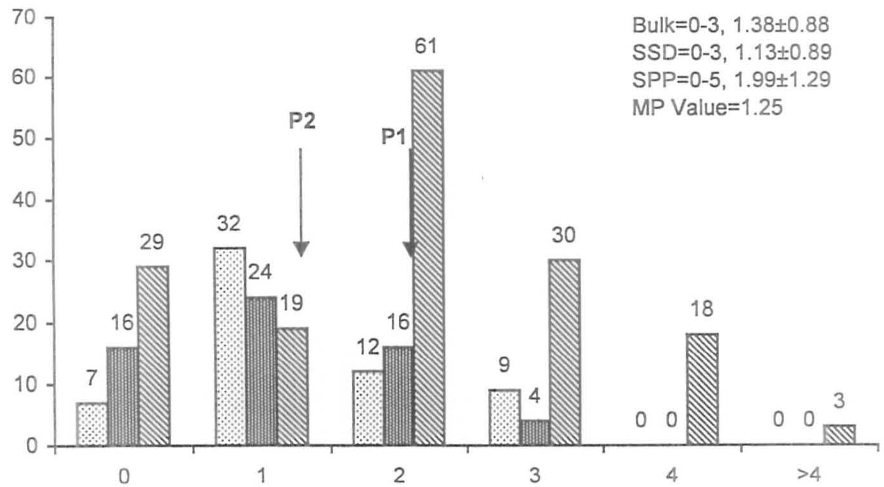


Fig. 4.1.13a. Comparison of three breeding methods for branches plant^{-1} in Mash 3/Mash 1 of blackgram at FJ

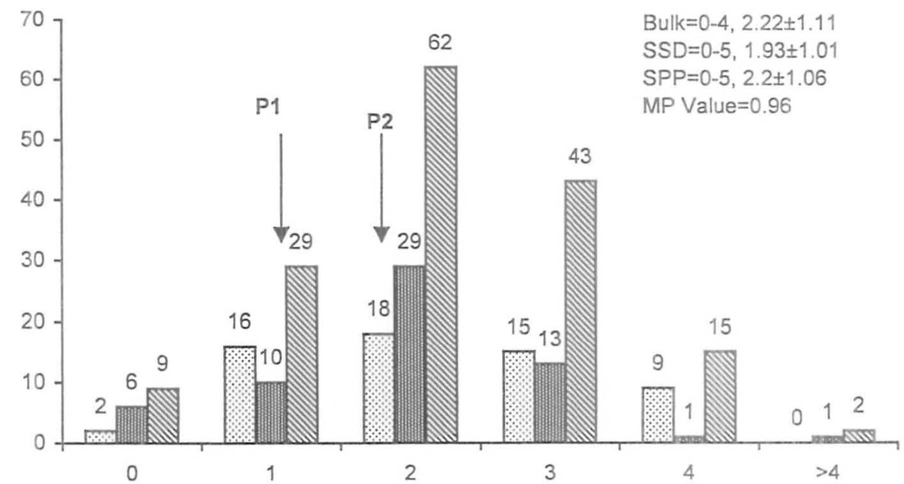


Fig. 4.1.13b. Comparison of three breeding methods for branches plant^{-1} in Mash 3/Mash 1 of blackgram at NARC

High mean values coupled with low range were observed in BM and SSD in hybrid Mash 3/9026 at NARC (Fig. 4.1.14a). Whereas, high ranges with high genetic variances were observed in SPP at both locations (Fig. 4.1.14a and b). In SPP, 13 plants were higher in branches at FJ with >4 branches plant^{-1} (Fig. 4.1.14a). Ninety percent produced higher branches plnat^{-1} in SSD in F_4 at NARC and 68.3% showed superiority in SPP at FJ.

Both SPP and SSD, breeding methods showed higher mean values at NARC while BM was observed similar at both the locations in the hybrid Mash 1/9026 (Fig. 4.1.15a and b). Single Seed Descent gave positive segregants at NARC, however, BM was observed negative for transgressive segregation at both the location. Ninety percent plants (54 out of 60 plants) showed superiority over mid parent in F_4 at NARC in SSD breeding method and it was followed by SPP at NARC (Table 4.1.4).

While comparing locations and breeding methods in the cross 9012/9025, high mean values were observed in BM and SPP at both the location (Fig. 4.1.16a and b). High frequency coupled with high branches was observed in SPP at FJ while at NARC all the methods were important for improving branches in this hybrid. Table 4.1.4 indicated that 88.3% plant progenies were superior in SSD in F_4 at NARC and Eighty-four plants out of 100 were superior in F_4 at FJ.

High mean values coupled with high ranges were observed in the cross 9020/Mash 3 in all the breeding methods at NARC in F_4 (Fig. 4.1.17b). However, BM failed to produce high number of branches, whereas SSD produced high branches at both the locations in this cross in F_4 generation. Single Plant Progenies produced high frequency of superior plants in case of branches at FJ than NARC Table 4.1.4. Single Seed Descent produced 70% superior plants in F_4 at NARC indicating the scope of selection to improve branches plant^{-1}.

The hybrid, 9020/Mash 1 revealed segregations in SSD and SPP at FJ, as compared to NARC in F_4 generation, that indicated the scope of selection in blackgram, although SPP was better at NARC (Fig. 4.1.18a and b). Forty plants out of 55 (72.73%) were higher for branches than mid parent in SPP at FJ in F_4 and it was followed by SPP at NARC in F_3 (Table 4.1.4). However, SPP and SSD at NARC produced superior plants to MP with 63.6 and 61.7 percent, respectively. The reciprocal hybrid (Mash 1/9020) revealed high mean value in SPP at FJ whereas at NARC Bulk Method and SSD were

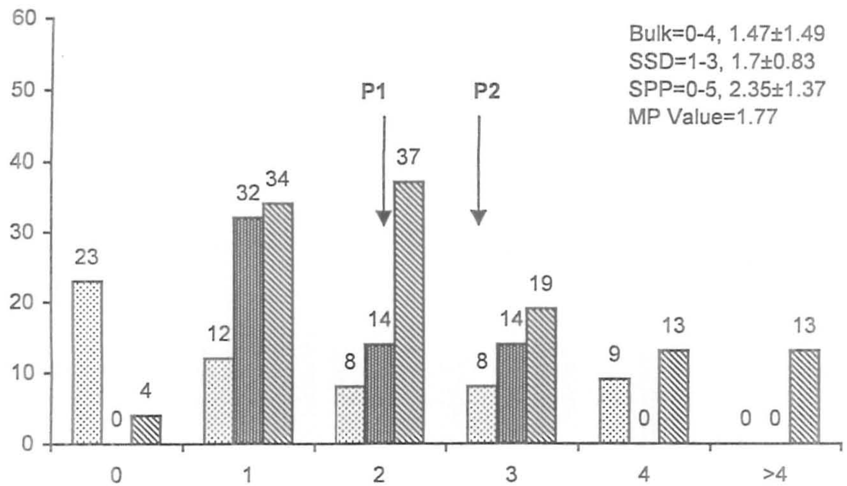


Fig. 4.1.14a. Comparison of three breeding methods for branches plant^{-1} in Mash 3/9026 of blackgram at FJ

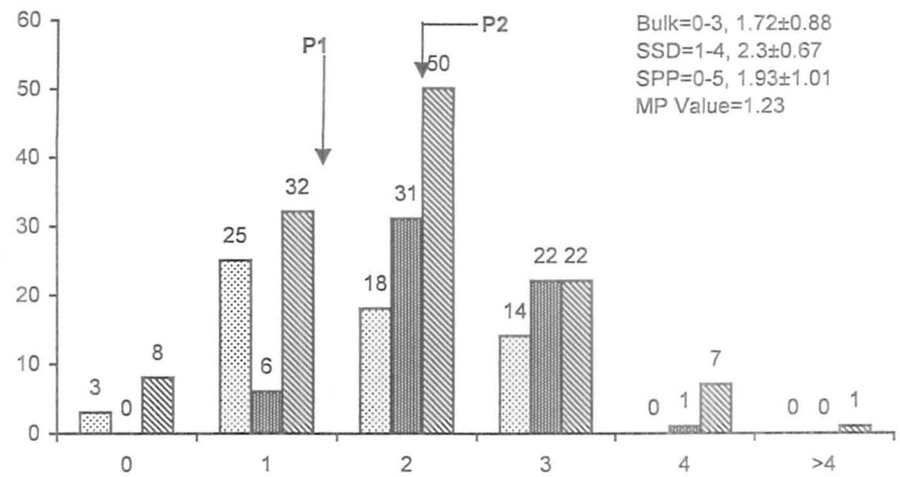


Fig. 4.1.14b. Comparison of three breeding methods for branches plant^{-1} in Mash 3/9026 of blackgram at NARC

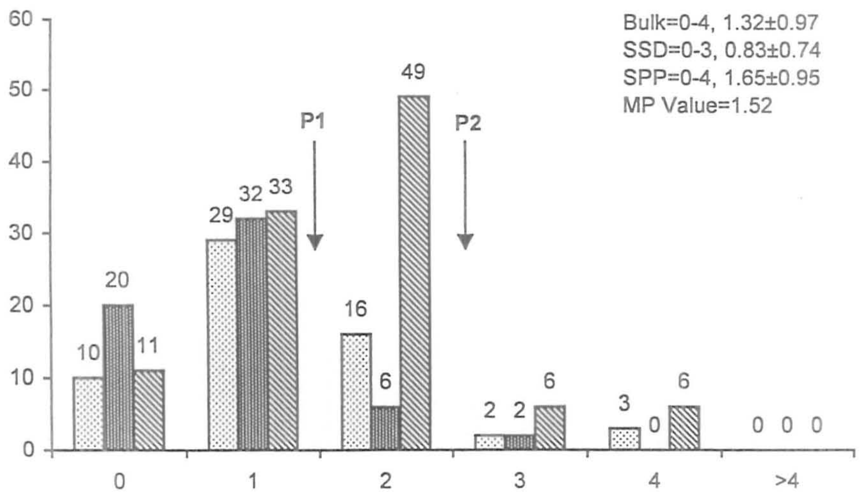


Fig. 4.1.15a. Comparison of three breeding methods for branches plant^{-1} in Mash 1/9026 of blackgram at FJ

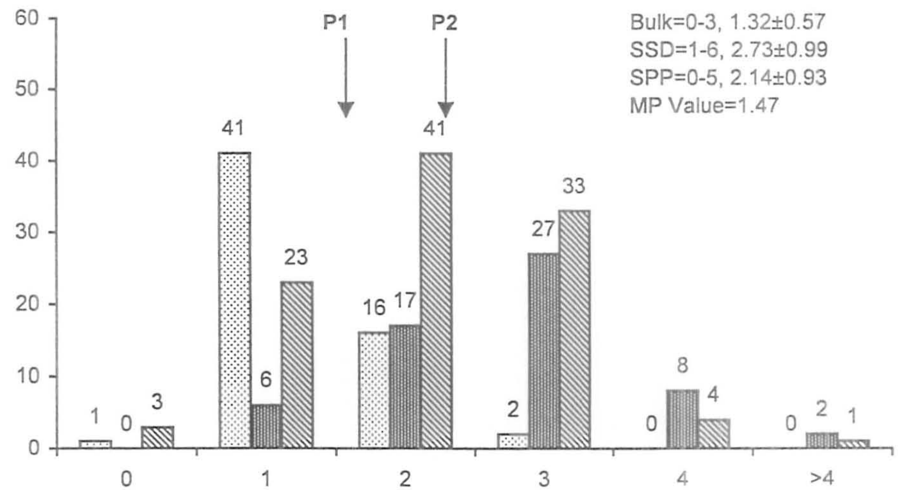


Fig. 4.1.15b. Comparison of three breeding methods for branches plant^{-1} in Mash 1/9026 of blackgram at NARC

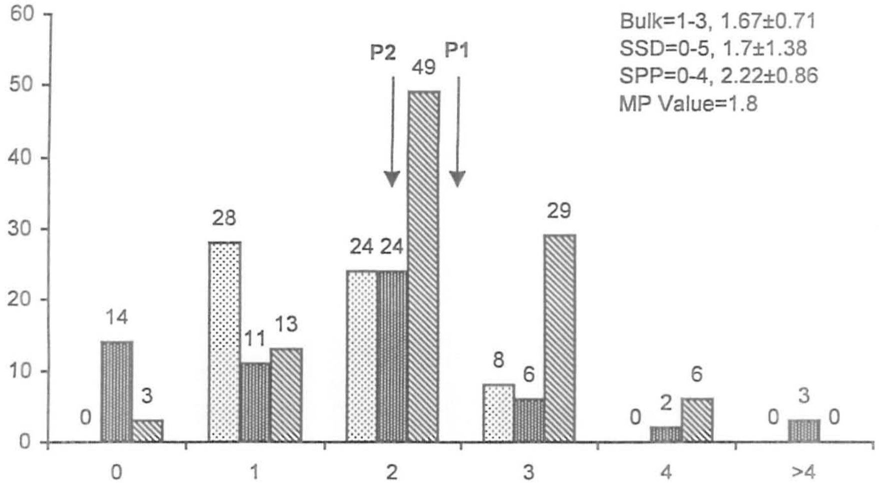


Fig. 4.1.16a. Comparison of three breeding methods for branches plant^{-1} in 9012/9025 of blackgram at FJ

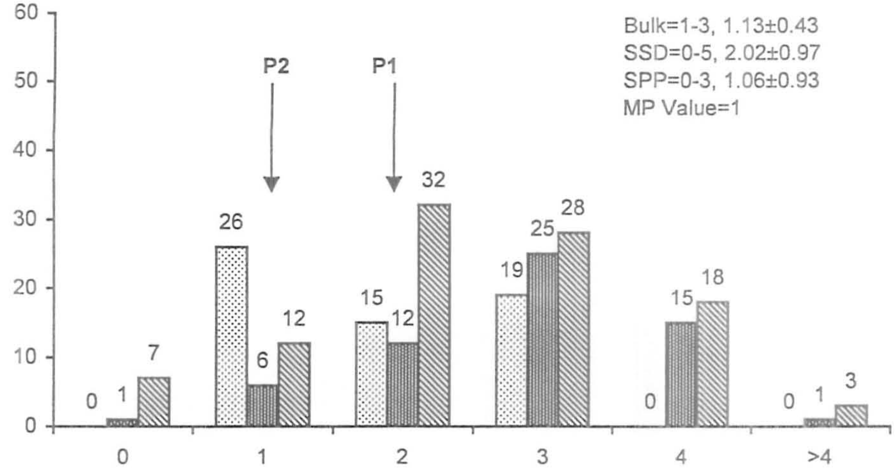


Fig. 4.1.16b. Comparison of three breeding methods for branches plant^{-1} in 9012/9025 of blackgram at NARC

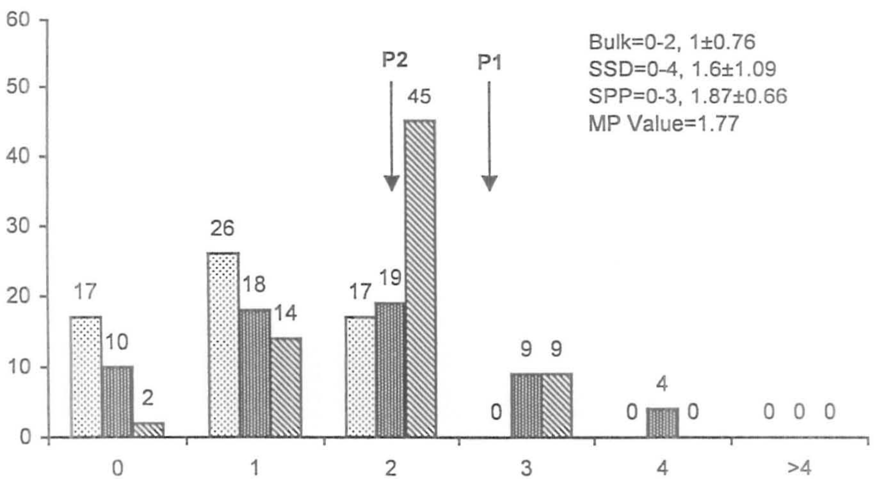


Fig. 4.1.17a. Comparison of three breeding methods for branches plant^{-1} in 9020/Mash 3 of blackgram at FJ

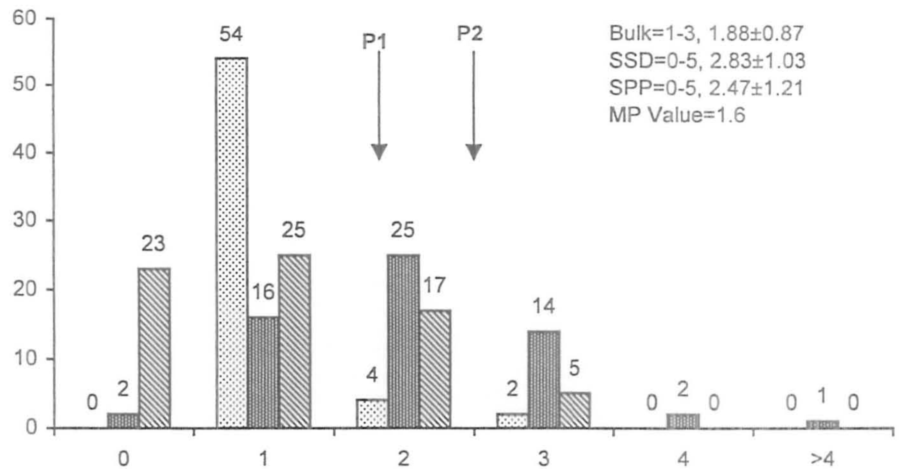


Fig. 4.1.17b. Comparison of three breeding methods for branches plant^{-1} in 9020/Mash 3 of blackgram at NARC

better (Fig. 4.1.19a and b). Single Seed Descent gave high range at FJ as compared to other two methods, whereas SPP was unable to produce plant with >3 branches plant^{-1} at NARC (Fig. 4.1.19b). Forty seven plants out of 50 were better than MP in F_3 at NARC (Table 4.1.4). However, at FJ in F_4 and at NARC F_2, 83.6% and 80.0% plant progenies were better for branches plant^{-1}over MP, respectively.

The hybrid 9020/9012 revealed high mean values in BM and SSD at FJ while low in SPP at NARC (Fig. 4.1.20a and b). Segregation skewed toward negative side in SPP at both the locations but higher range coupled with low frequency was observed in BM at both the locations. Bulk Method produced plants which were with >4 branches plant^{-1} at both the locations that indicated validity of this method in this hybrid. It was observed in general that breeding methods were influenced by the interaction of genetic makeup of location and hybrid.

Table 4.1.4 revealed that at NARC, Bulk Method produced 63.3% (38 out of 60 plants) plants superior to MP in F_4 and it was followed by SPP in F_3. However, BM at FJ and SSD at NARC were equal in production of better plants for branches that indicated usefulness of these methods in this cross.

The hybrid, 9012/9020 revealed high mean values coupled with high range in all the breeding methods at FJ (Fig. 4.1.21a). Negative segregation was achieved in BM at both the locations. At NARC, none of the breeding methods produced any plant with >3 branches plant^{-1}. Eighty-four percent plant progenies were superior in F_3 at NARC in SPP (Table 4.1.4). In F_4, at NARC Single Plant Progenies produced 80% superior plant, whereas 58.2 % plants were better at FJ.

The hybrid, 9025/9026 revealed higher mean values in SSD and SPP at FJ, while at NARC Single Plant Progenies excelled in branches (Fig. 4.1.22a and b). High range was observed in SSD at both the locations, whereas BM and SPP revealed narrow range coupled with high frequency at both the locations. Single Plant Progenies were unable to produce >3 branches plant^{-1} at NARC. Single Plant Progenies at FJ produced 93% plants superior over MP in F_4 while 91% at NARC (Table 4.1.4). However, SSD produced 55% superior plants over MP at FJ in F_4. Based on these results it could be suggested that selection for branches may be practiced from F_4 or delayed to later generations.

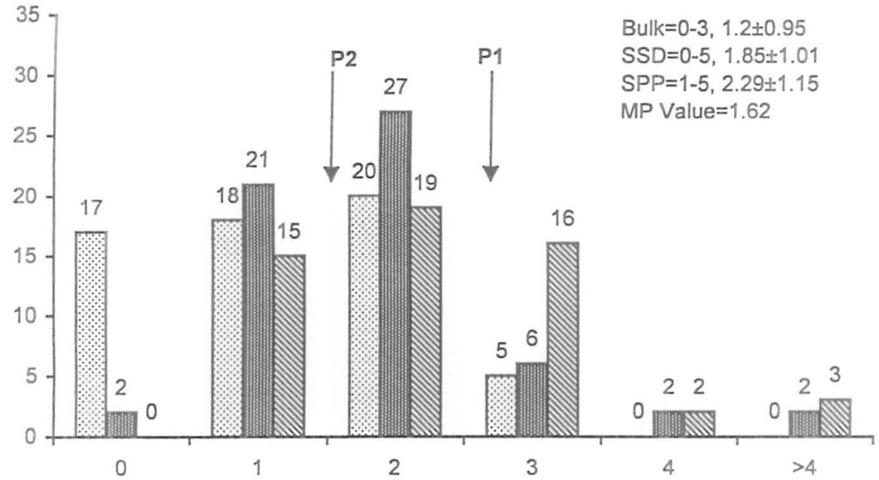


Fig. 4.1.18a. Comparison of three breeding methods for branches plant^{-1} in 9020/Mash 1 of blackgram at FJ

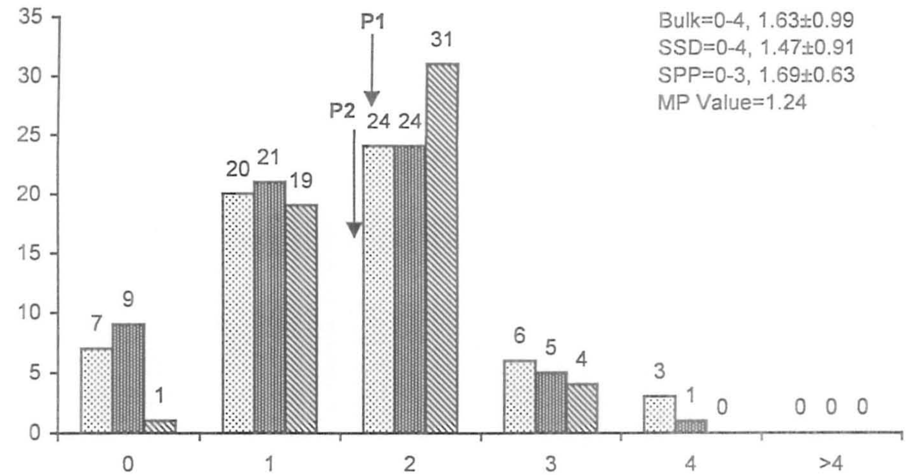


Fig. 4.1.18b. Comparison of three breeding methods for branches plant^{-1} in 9020/Mash 1 of blackgram at NARC

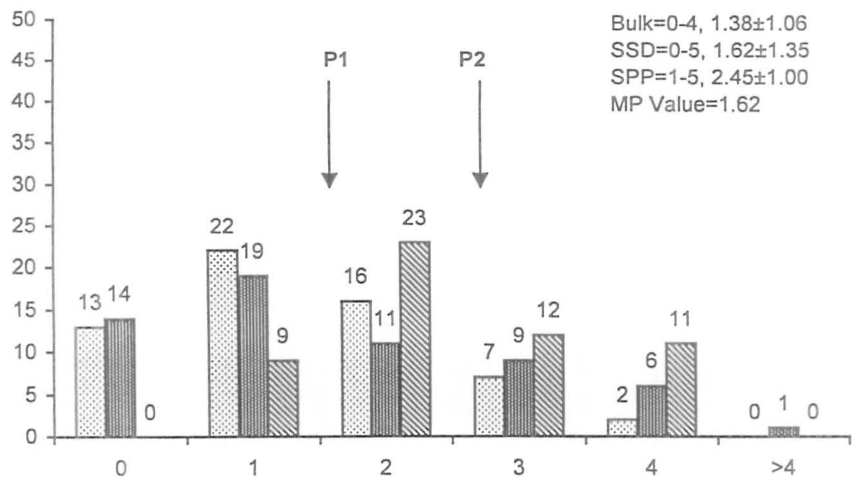


Fig. 4.1.19a. Comparison of three breeding methods for branches plant^{-1} in Mash 1/9020 of blackgram at FJ

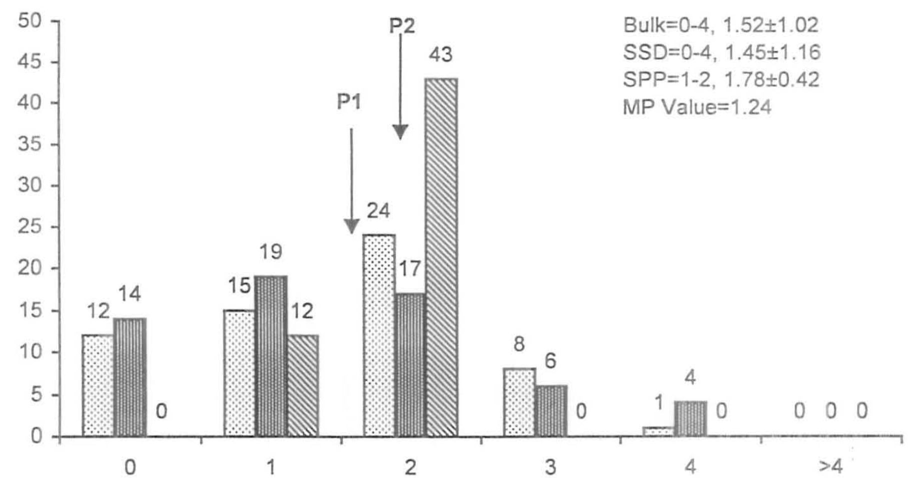


Fig. 4.1.19b. Comparison of three breeding methods for branches plant^{-1} in Mash 1/9020 of blackgram at NARC

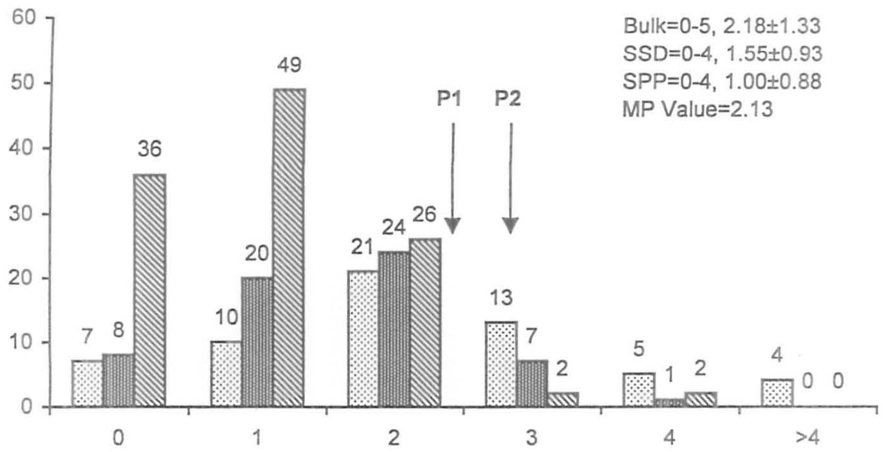


Fig. 4.1.20a. Comparison of three breeding methods for branches plant^{-1} in 9020/9012 of blackgram at FJ

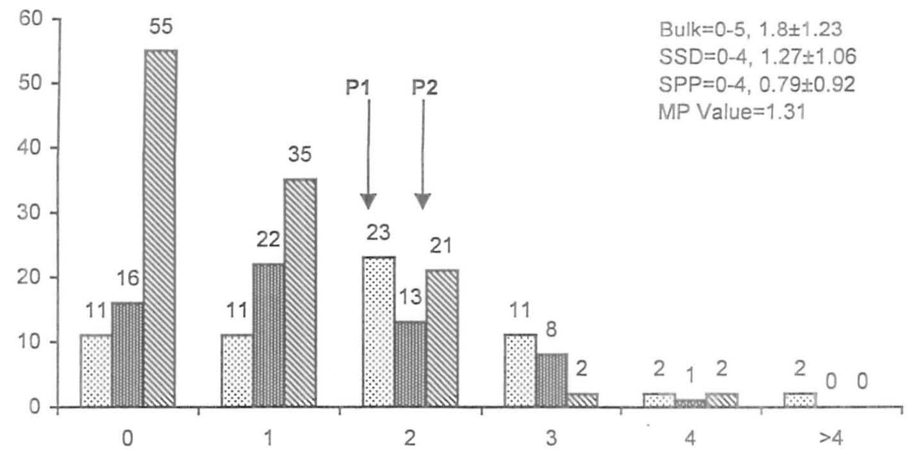


Fig. 4.1.20b. Comparison of three breeding methods for branches plant^{-1} in 9020/9012 of blackgram at NARC

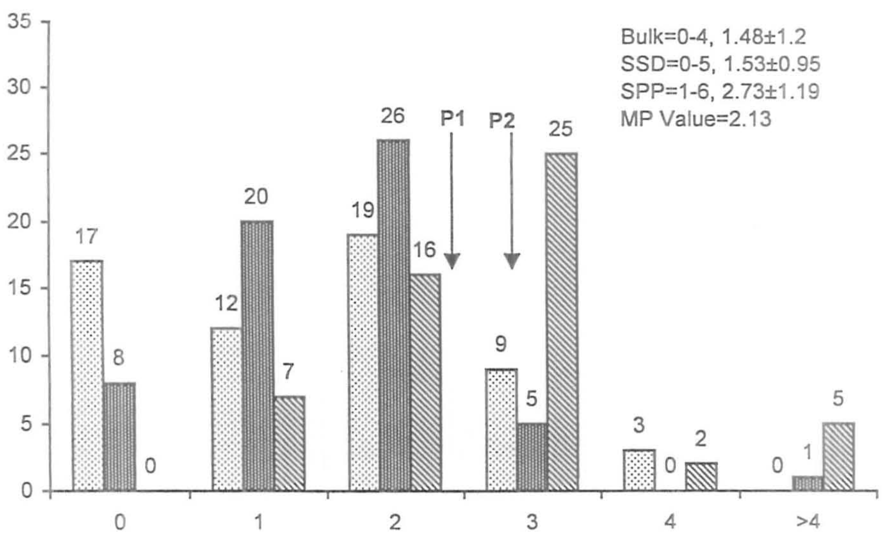


Fig. 4.1.21a. Comparison of three breeding methods for branches plant^{-1} in 9012/9020 of blackgram at FJ

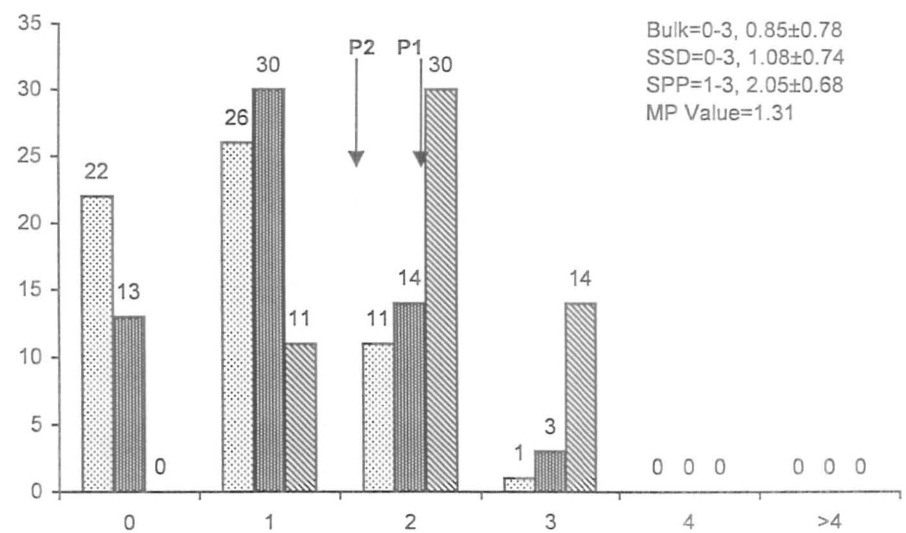


Fig. 4.1.21b. Comparison of three breeding methods for branches plant^{-1} in 9012/9020 of blackgram at NARC

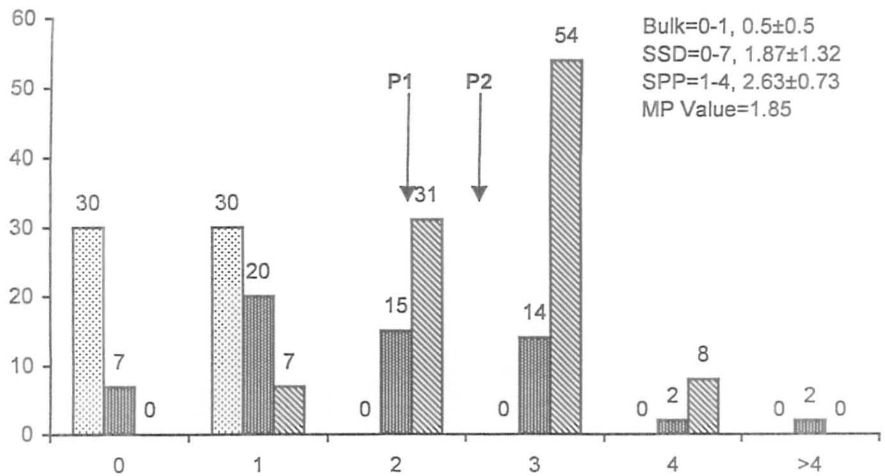


Fig. 4.1.22a. Comparison of three breeding methods for branches plant^{-1} in 9025/9026 of blackgram at FJ

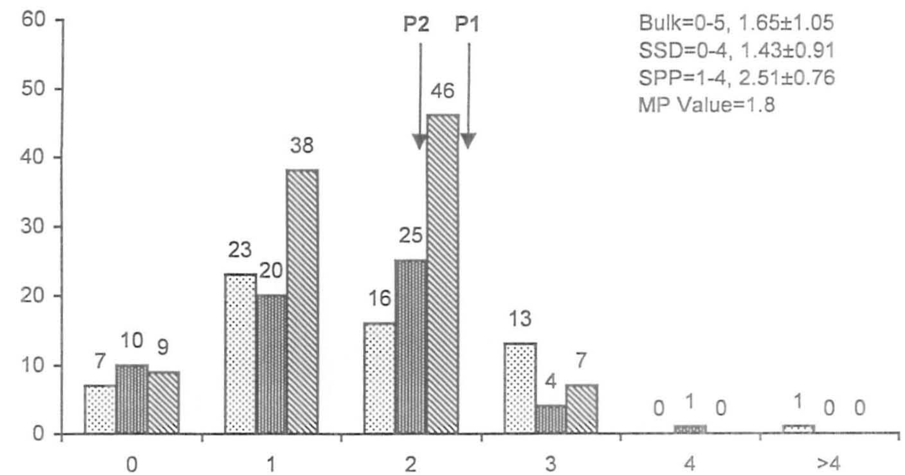


Fig. 4.1.22b. Comparison of three breeding methods for branches plant^{-1} in 9025/9026 of blackgram at NARC

Table 4.1.4: Number of plants and their percentage over mid parent value in branches plant^{-1} in 11 crosses at two locations.

Gen.	Location	Br. M.	M P Value	No. of sample collected	No. of plants over MP	%age over MP	M P Value	No. of sample collected	No. of plants over MP	%age over MP	M P Value	No. of sample collected	No. of plants over MP	%age over MP
			9025/Mash 1				**Mash 3/Mash 1**				**Mash 3/9026**			
F_2	NARC	SPP	3.00	30	9	30.00	3.00	30	24	80.00	3.00	30	15	50.00
F_3	NARC	SPP	2.20	50	13	26.00	2.30	50	30	60.00	2.10	50	15	38.00
F_4	NARC	SPP	1.54	145	125	86.21	0.96	160	151	94.38	1.23	120	80	66.67
F_4	FJ	SPP	1.34	145	86	59.31	1.25	160	112	70.00	1.77	120	82	68.33
F_4	FJ	BM	1.34	60	15	25.00	1.25	60	21	35.00	1.77	60	25	41.67
F_4	NARC	BM	1.54	60	16	26.67	0.96	60	58	96.67	1.23	60	32	53.33
F_4	FJ	SSD	1.34	60	9	15.00	1.25	60	20	33.33	1.77	60	28	46.67
F_4	NARC	SSD	1.54	60	45	75.00	0.96	60	54	90.00	1.23	60	54	90.00
			Mash 1/9026				**9012/9025**				**9020/Mash 3**			
F_2	NARC	SPP	3.10	30	12	40.00	3.45	30	6	20.00	3.20	30	9	30.00
F_3	NARC	SPP	2.10	50	20	40.00	2.05	50	4	8.00	1.90	50	45	90.00
F_4	NARC	SPP	1.47	105	71	67.62	1.60	100	81	81.00	1.00	70	22	31.00
F_4	FJ	SPP	1.25	105	61	58.00	1.80	100	84	84.00	1.77	70	54	77.14
F_4	FJ	BM	1.25	60	21	35.00	1.80	60	32	53.33	1.77	60	17	28.33
F_4	NARC	BM	1.47	60	18	30.00	1.60	60	34	56.67	1.00	60	6	10.00
F_4	FJ	SSD	1.25	60	8	13.33	1.80	60	35	58.33	1.77	60	32	53.33
F_4	NARC	SSD	1.47	60	54	90.00	1.60	60	53	88.33	1.00	60	42	70.00
			9020/Mash 1				**Mash 1/9020**				**9020/9012**			
F_2	NARC	SPP	3.30	30	15	50.00	3.30	30	24	80.00	3.75	30	6	20.00
F_3	NARC	SPP	1.90	50	36	72.00	1.90	50	47	94.00	1.75	50	31	62.00
F_4	NARC	SPP	1.24	55	35	63.64	1.24	55	43	78.18	1.31	115	25	21.74
F_4	FJ	SPP	1.62	55	40	72.73	1.62	55	46	83.64	2.13	115	4	3.48
F_4	FJ	BM	1.62	60	25	41.67	1.62	60	25	41.67	2.13	60	22	36.67
F_4	NARC	BM	1.24	60	33	55.00	1.24	60	33	55.00	1.31	60	38	63.33
F_4	FJ	SSD	1.62	60	37	61.67	1.62	60	27	45.00	2.13	60	8	13.33
F_4	NARC	SSD	1.24	60	30	50.00	1.24	60	27	45.00	1.31	60	22	36.67
			9012/9020				**9025/9026**							
F_2	NARC	SPP	3.75	30	6	20.00	3.00	30	12	40.00				
F_3	NARC	SPP	1.75	50	42	84.00	2.00	50	2	4.00				
F_4	NARC	SPP	1.31	55	44	80.00	1.80	100	91	91.00				
F_4	FJ	SPP	2.13	55	32	58.18	1.85	100	93	93.00				
F_4	FJ	BM	2.13	60	12	20.00	1.85	60	0	0.00				
F_4	NARC	BM	1.31	60	12	20.00	1.80	60	30	50.00				
F_4	FJ	SSD	2.13	60	6	10.00	1.85	60	33	55.00				
F_4	NARC	SSD	1.31	60	17	28.33	1.80	60	30	50.00				

4.1.3 Number of Pods

High number of pods leads to more grain yield in most of the legumes crops. While comparing breeding methods over two locations in the hybrid 9025/Mash 1, high mean value in BM and SPP were observed at Fateh Jang, while at NARC this value was high in SSD (Fig. 4.1.23a and b). Bulk Method produced negative transgressive segregation at both the locations. High range coupled with high frequency was achieved in SPP at both the locations. Maximum plants (92 out of 145) which were 63.5% were superior over MP at FJ in SPP in F_4. Thirty-five out of 60 (58.3%) and 25 out of 60 plants (41.67%) were superior in SSD at FJ and NARC in F_4, respectively (Table 4.1.5). The results obtained from this hybrid from different methods and in different generations indicated that SSD and SPP were better to select plants with higher pods plant^{-1}.

The hybrid Mash 3/Mash 1 produced high mean value coupled with high variance and high range in SPP at both the locations (Fig. 4.1.24a and b). High mean along with low range was also observed in SSD at both the locations, whereas BM produced low frequency with high range at both the location. Single Seed Descent was unable to produce any plant with >45 pods at both the location showing limitation of adoption of this method to high number of pods plant^{-1}.

Twenty-four plants out of 30 were observed superior in F_2 at NARC and it was followed by progenies SPP in F_4 at NARC (Table 4.1.5). This method was especially good in farmer's condition i.e., FJ location. Results comparing breeding methods over the generations revealed that SSD produced 71.67% superior plant progenies (43 out of 60) at FJ in F_4. It was concluded that high number of pods per plant could be achieved in SPP and SSD at both the locations in this hybrid. This hybrid involved both the approved varieties hence short duration, high yielding segregants are expected that could be selected in F_4 or next year.

In the hybrid Mash 3/9026 high mean values coupled with high range were observed in SPP at both the locations (Fig. 4.1.25a and b). However, SSD produced higher range at NARC but it failed to produce plants with >35 pods plant^{-1} at FJ. While comparing locations and methods it was observed that maximum 73.33% (44 out of 60) plants were higher over MP in SSD at NARC (Table 4.1.5). Single Plant Progenies in F_2 produced higher pods plant^{-1} at NARC. However, this hybrid indicated importance of SPP that could produce superior progenies.

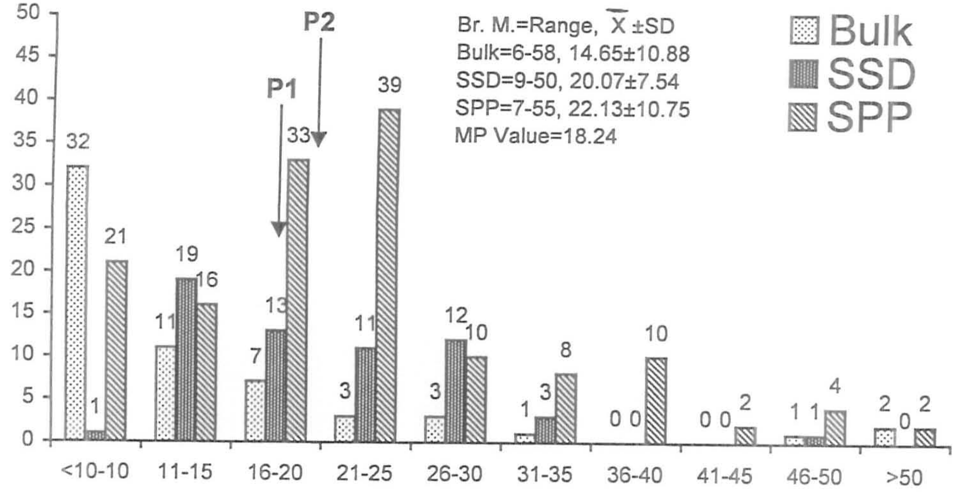


Fig. 4.1.23a. Comparison of three breeding methods for number of pods plant^{-1} in 9025/Mash 1 of blackgram at FJ

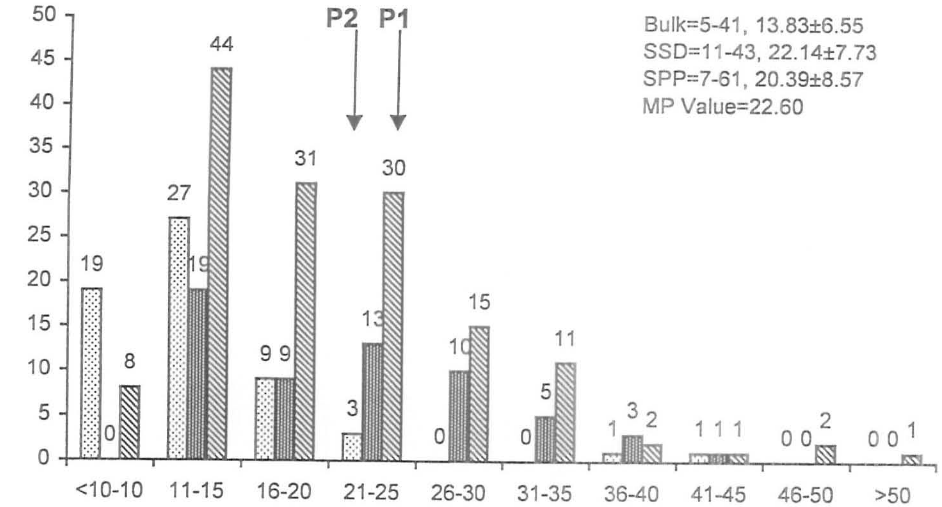


Fig. 4.1.23b. Comparison of three breeding methods for number of pods plant^{-1} in 9025/Mash 1 of blackgram at NARC

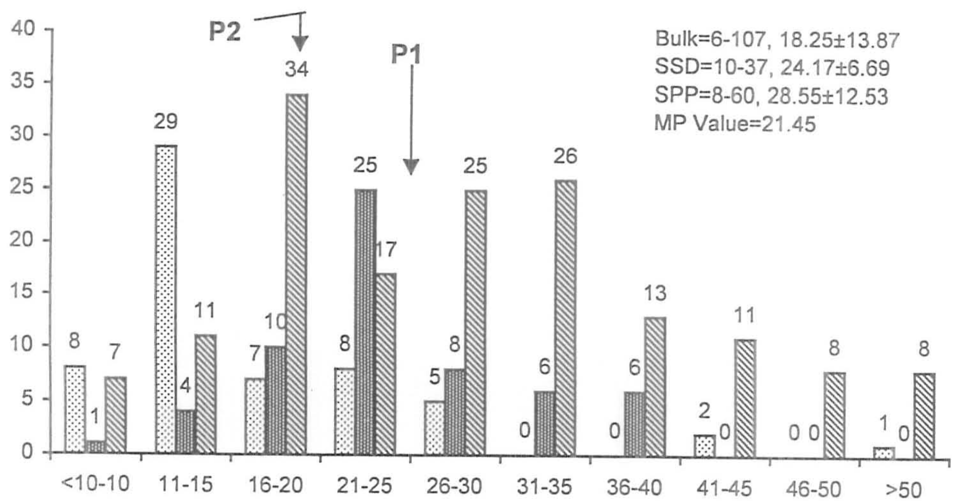


Fig. 4.1.24a. Comparison of three breeding methods for number of pods plant^{-1} in Mash 3/Mash 1 of blackgram at FJ

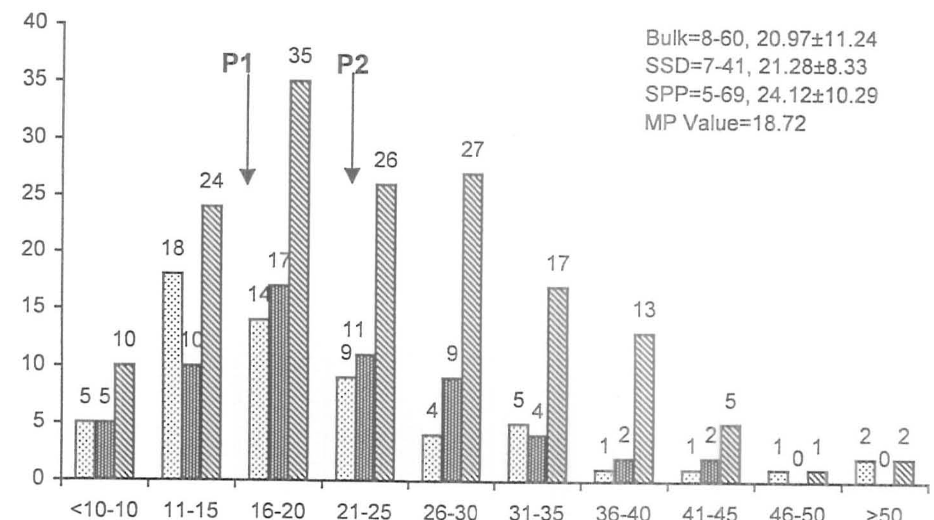


Fig. 4.1.24b. Comparison of three breeding methods for number of pods plant^{-1} in Mash 3/Mash 1 of blackgram at NARC

Mash 1/9026 revealed high mean values coupled with high frequency for pods plant^{-1} in BM and SPP at FJ. Single Seed Descent and SPP produced higher ranges for this trait at both the locations (Fig. 4.1.26a and b). Bulk Method did not produce segregants with higher pods plant^{-1}. Single Seed Descent produced 63.33% plants better over MP in F_4 at NARC. It was concluded that this hybrid did not qualify to select superior plant/progenies in all the three methods although few plants/progenies were observed at higher side.

The hybrid 9012/9025 exhibited high mean values at FJ in all the breeding methods while high ranges were recorded in SPP and SSD at both the locations (Fig. 4.1.27a and b). The frequency observed in SPP at FJ was wider as compared to NARC. Bulk Method could not prove its worth to improved pod length in this cross. Maximum 83% progenies in SPP were better than MP at NARC and it was followed by FJ in the same method and generation (F_4) where 64% progenies were superior (Table 4.1.5). Single Seed Descent revealed 61.67% and 43.33% plant populations which were superior over MP at both the locations.

The hybrid 9020/Mash 3 produced higher transgressive segregation coupled with high frequency at FJ (Fig. 4.1.28a). However, this method revealed normal distribution at NARC with narrow range (Fig. 4.1.28b). Single Seed Descent produced similar results as in SPP but few plants with > 40 pods plant^{-1} were observed in SSD. Single Seed Descent produced 60% better plants/progenies then MP in F_4 at NARC (Table 4.1.5). Forty-five percent plant progenies in BM showed superiority in F_4 at NARC and it was followed by SPP at FJ.

The 9020/Mash 1 showed high mean values and range in BM and SSD at NARC and FJ (Fig. 4.1.29a and b). Transgressive segregation coupled with high frequency was observed in SPP at both the locations, especially at FJ where nine progenies were in the range of 36 – 40 pods plant^{-1}. Forty plant progenies out of 60 were superior in pods plant^{-1} over mid parent in BM and SSD at NARC (Table 4.1.5). While in SPP, 56.66% progenies were better and 50% were better in F_2 over MP at NARC.

Mash 1/9020 revealed high mean values in SSD and SPP at NARC, whereas in BM it was high at FJ (Fig. 4.1.30a and b). Comparatively higher transgressive segregants were observed at NARC. Single Seed Descent and BM were able to produce few plants with more number of pods plant^{-1}. While comparing breeding methods 70% plant

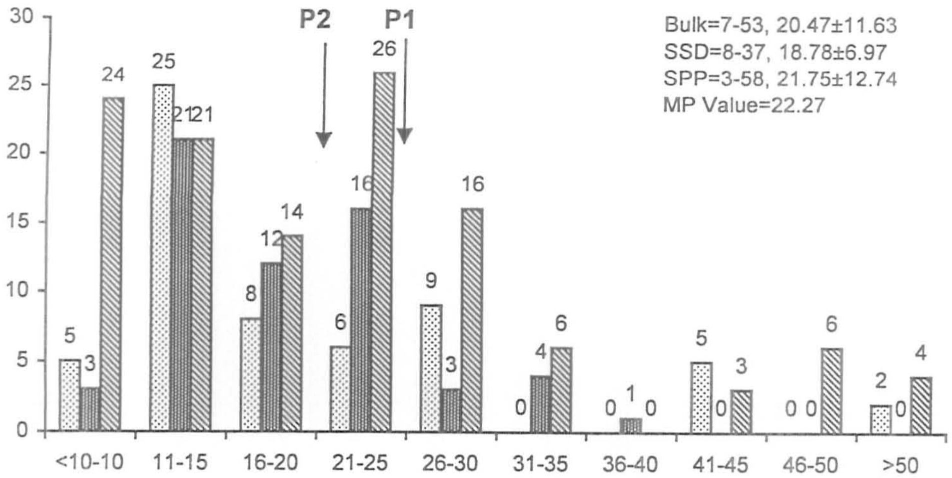


Fig. 4.1.25a. Comparison of three breeding methods for number of pods plant^{-1} in Mash 3/9026 of blackgram at FJ

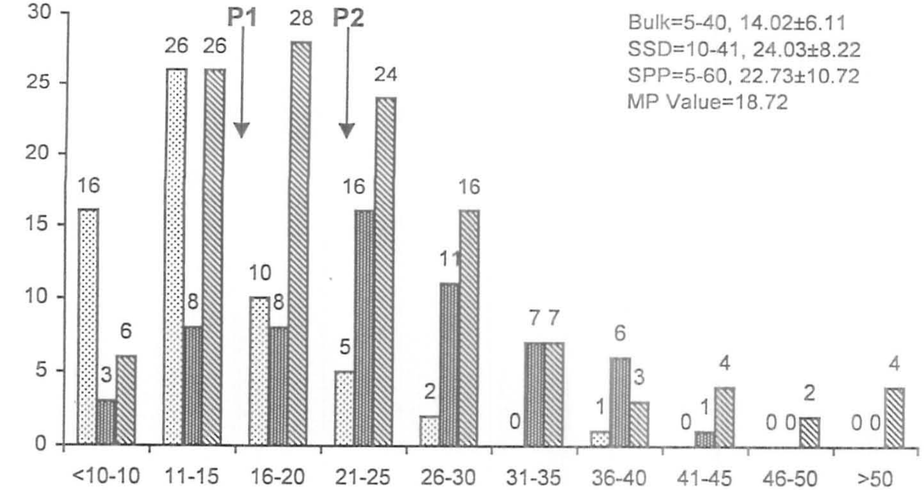


Fig. 4.1.25b. Comparison of three breeding methods for number of pods plant^{-1} in Mash 3/9026 of blackgram at NARC

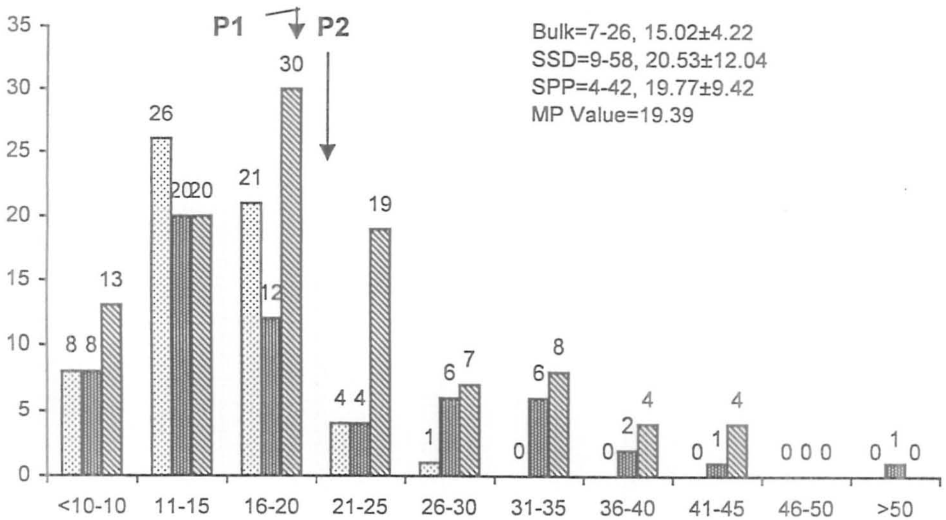


Fig. 4.1.26a. Comparison of three breeding methods for number of pods plant^{-1} in Mash 1/9026 of blackgram at FJ

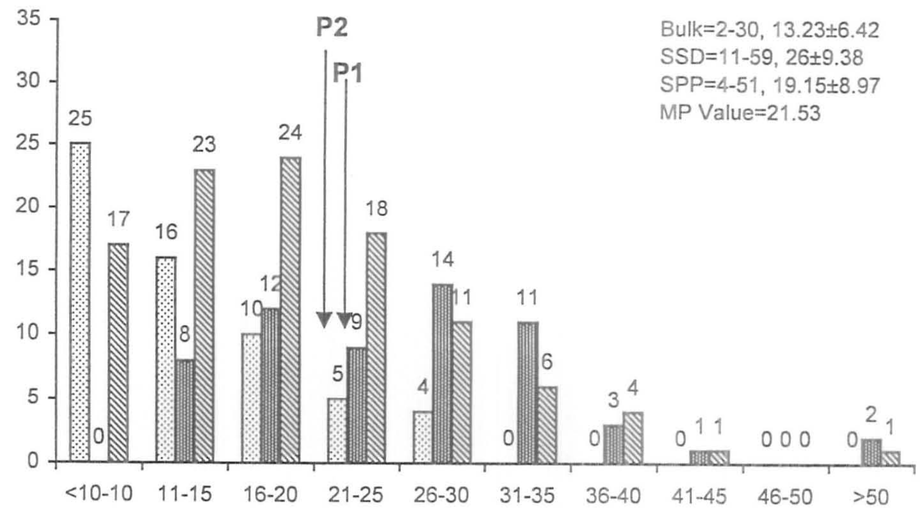


Fig. 4.1.26b. Comparison of three breeding methods for number of pods plant^{-1} in Mash 1/9026 of blackgram at NARC

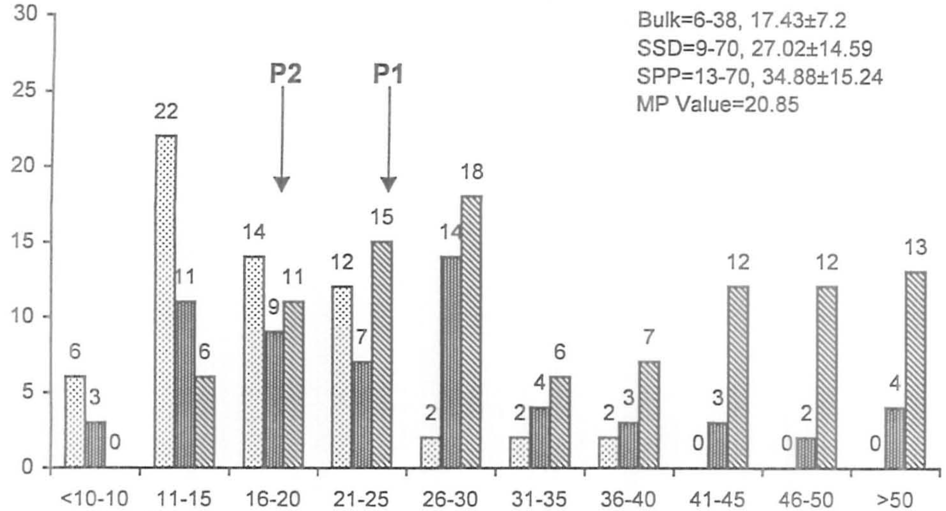


Fig. 4.1.27a. Comparison of three breeding methods for number of pods plant^{-1} in 9012/9025 of blackgram at FJ

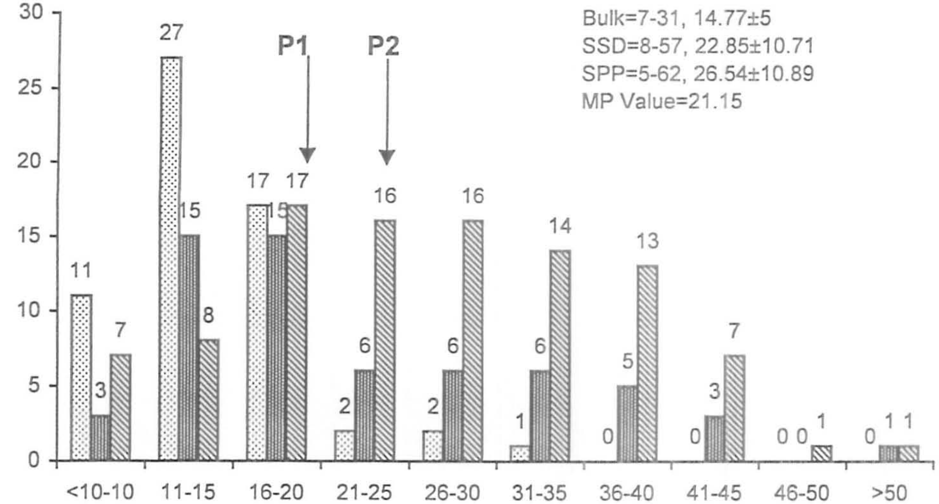


Fig. 4.1.27b. Comparison of three breeding methods for number of pods plant^{-1} in 9012/9025 of blackgram at NARC

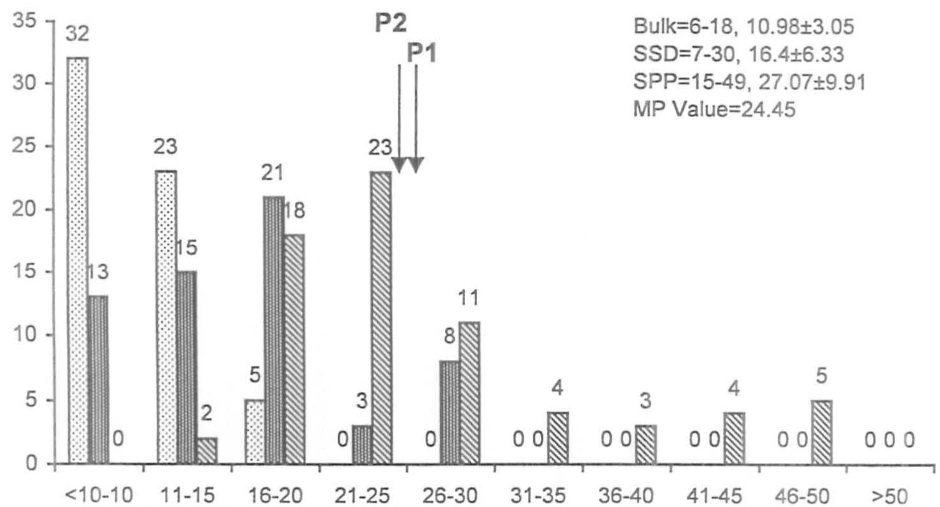


Fig. 4.1.28a Comparison of three breeding methods for number of pods plant^{-1} in 9020/Mash 3 of blackgram at FJ

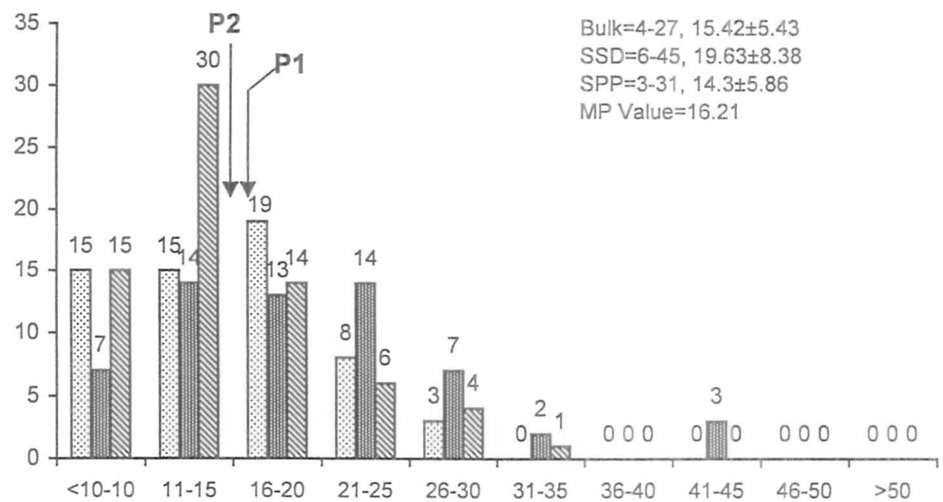


Fig. 4.1.28b. Comparison of three breeding methods for number of pods plant^{-1} in 9020/Mash 3 of blackgram at NARC

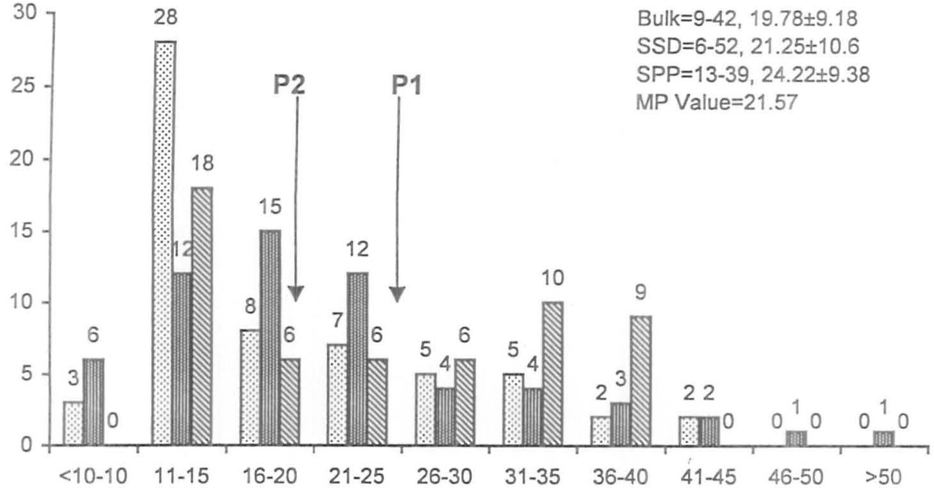


Fig. 4.1.29a. Comparison of three breeding methods for number of pods plant^{-1} in 9020/Mash 1 of blackgram at Fateh Jang

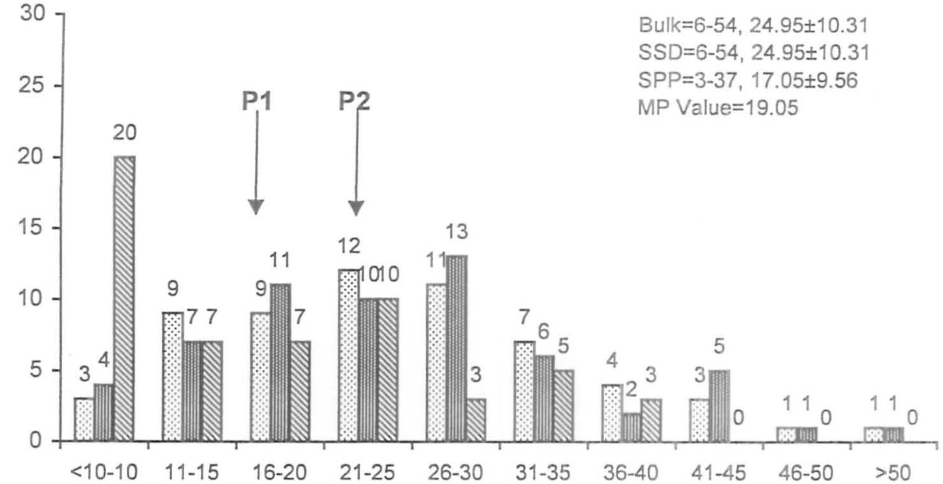


Fig. 4.1.29b. Comparison of three breeding methods for number of pods plant^{-1} in 9020/Mash 1 of blackgram at NARC

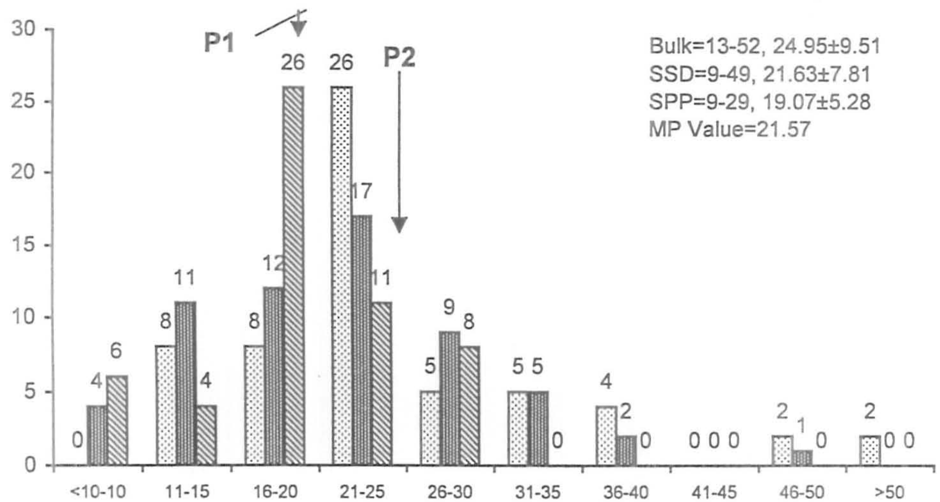


Fig. 4.1.30a. Comparison of three breeding methods for number of pods plant^{-1} in Mash 1/9020 of blackgram at FJ

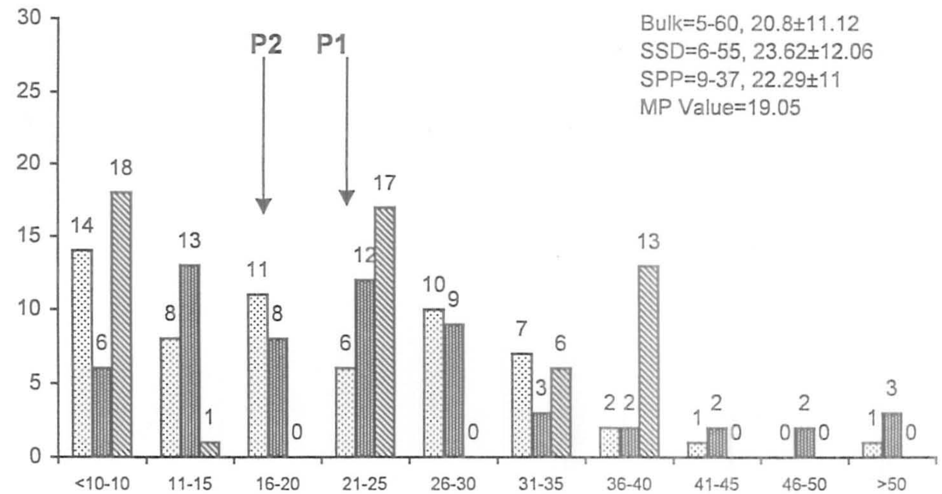


Fig. 4.1.30b. Comparison of three breeding methods for number of pods plant^{-1} in Mash 1/9020 of blackgram at NARC

progenies were observed better in SPP over mid parent in F_2 and 65.45% in F_4 at NARC (Table 4.1.5). However, BM at FJ and SSD at NARC produced 63.33% and 56.67% superior plant progenies, respectively.

The hybrid 9020/9012 revealed high range coupled with low frequency in BM and SSD at both the locations (Fig. 4.1.31a and b). Single Plant Progenies gave high frequency but transgressing towards negative side indicating no scope for selecting segregants with higher pods. Similarly, SPP failed to produce superior plant at both the locations. Forty-one out of 60 were better over MP in SSD at NARC, it was followed by BM at both the locations where 33 and 31 plant progenies were better over mid parent, respectively (Table 4.1.5).

The hybrid 9012/9020 revealed high mean values in SPP as shown in Fig. 4.1.32a and b. Bulk Method and SPP failed to produce high pods plant^{-1} at both the locations. Single Seed Descent also produced negative transgressive segregation; therefore this cross in general did not exhibit suitable segregants for this trait. Forty-six pods plant^{-1} out of 55 in SPP were better over MP at FJ, followed by SSP at NARC where 49.09% plant progenies were superior (Table 4.1.5).

The results in hybrid 9025/9026 revealed high mean values coupled with high ranges in SSD and SPP at both the locations (Fig. 4.1.33a and b). However, BM was unable to produce plants with >40 pods. While comparing the SPP breeding method over the generation, 72% plant progenies were superior over MP, followed by SPP in F_2 where 60% plant progenies were superior (Table 4.1.5).

4.1.4 5 Pods Length

Pod length plays an important role in improving grain yield. Narrow range for this important trait has been observed in blackgram like most of the legumes. While discussing the results of pod length in this study, five pods were randomly sampled from each selected plant and their length was measured in centimeters (cm). The results observed in cross 9025/Mash 1 at both the locations for three breeding methods were almost similar except in SSD where two plants gave >25cm pod length at NARC (Fig. 4.1.34a and b). Minimum differences were observed in mean values and ranges except in the range of SSD, where it was high at FJ. The remaining maximum range for all the breeding methods were close to mid parent at both the locations. Sixty-five percent plant

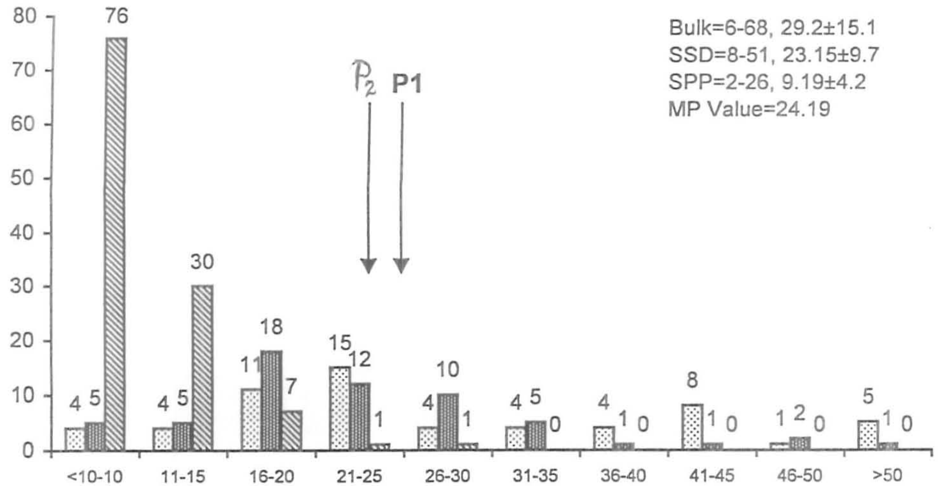


Fig. 4.1.31a. Comparison of three breeding methods for number of pods plant^{-1} in 9020/9012 of blackgram at FJ

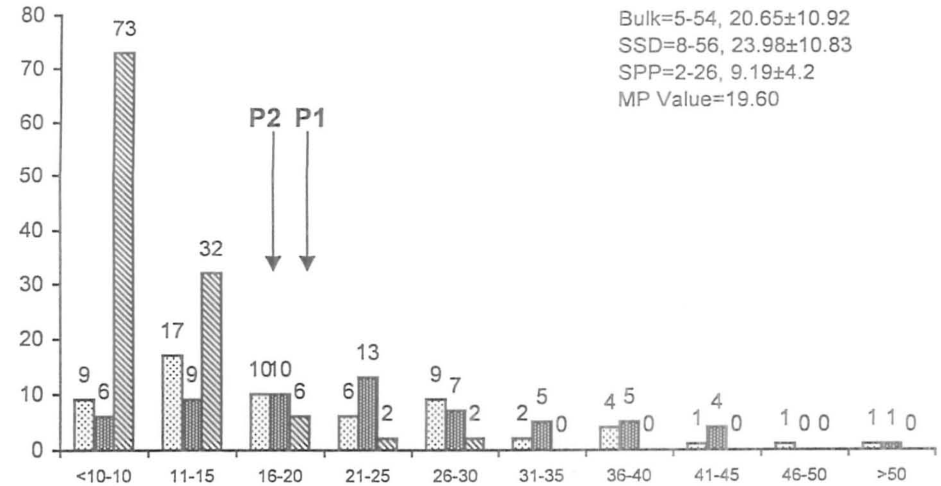


Fig. 4.1.31b. Comparison of three breeding methods for number of pods plant^{-1} in 9020/9012 of blackgram at NARC

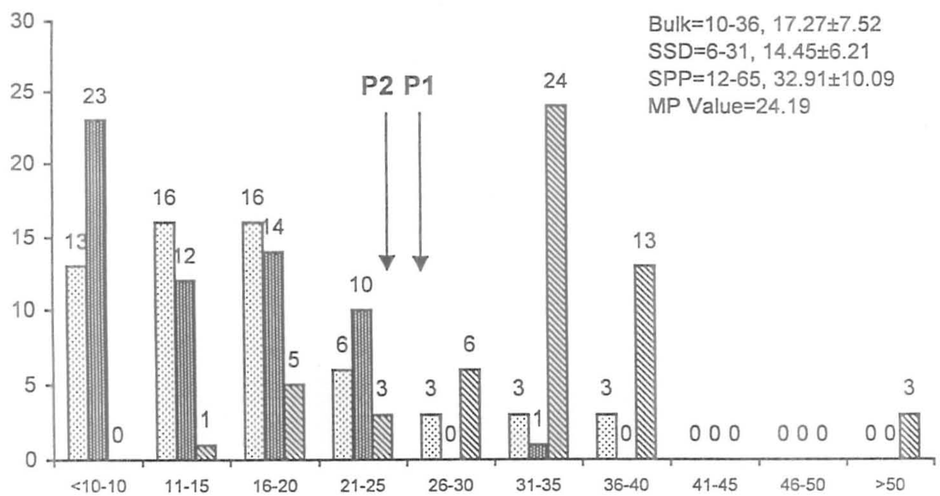


Fig. 4.1.32a. Comparison of three breeding methods for number of pods plant^{-1} in 9012/9020 of blackgram at FJ

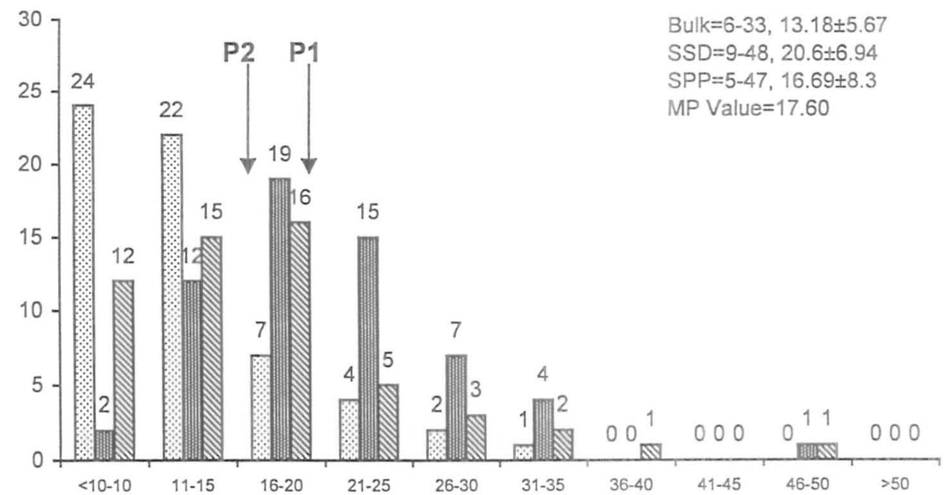


Fig. 4.1.32b. Comparison of three breeding methods for number of pods plant^{-1} in 9012/9020 of blackgram at NARC

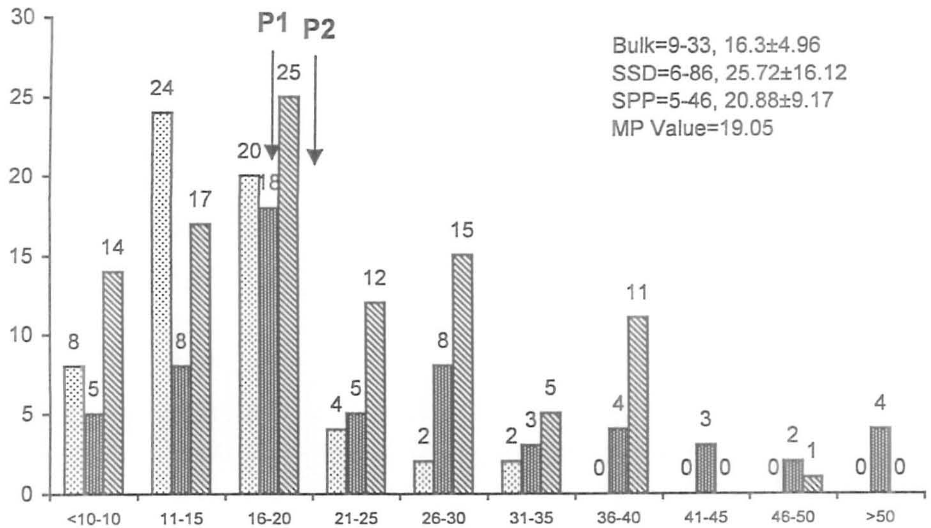


Fig. 4.1.33a. Comparison of three breeding methods for number of pods plant^{-1} in 9025/9026 of blackgram at FJ

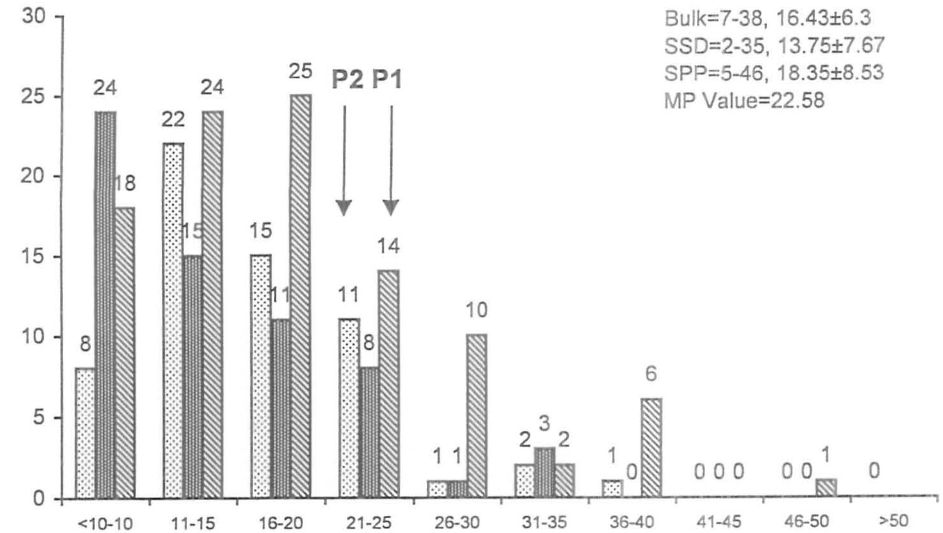


Fig. 4.1.33b. Comparison of three breeding methods for number of pods plant^{-1} in 9025/9026 of blackgram at NARC

Table 4.1.5: Number of plants and their percentage over mid parent value in number of pods plant^{-1} in 11 crosses at two locations.

Gen.	Location	Br. M.	M P Value	No. of sample collected	No. of plants over MP	%age over MP	M P Value	No. of sample collected	No. of plants over MP	%age over MP	M P Value	No. of sample collected	No. of plants over MP	%age over MP
			9025/Mash 1				Mash 3/Mash 1				Mash 3/9026			
F_2	NARC	SPP	44.50	30	12	40.00	48.30	30	24	80.00	40.90	30	18	60.00
F_3	NARC	SPP	25.90	50	13	26.00	36.00	50	9	18.00	25.35	50	16	32.00
F_4	NARC	SPP	22.60	145	47	32.41	18.72	160	109	68.13	18.72	120	71	59.17
F_4	FJ	SPP	18.24	145	92	63.45	21.45	160	108	67.50	22.27	120	54	45.00
F_4	FJ	BM	18.24	60	12	20.00	21.45	60	16	26.67	22.27	60	18	30.00
F_4	NARC	BM	22.60	60	3	5.00	18.72	60	26	43.33	18.72	60	10	16.67
F_4	FJ	SSD	18.24	60	35	58.33	21.45	60	43	71.67	22.27	60	13	21.67
F_4	NARC	SSD	22.60	60	25	41.67	18.72	60	37	61.67	18.72	60	44	73.33
			Mash 1/9026				9012/9025				9020/Mash 3			
F_2	NARC	SPP	43.20	30	12	40.00	47.35	30	9	30.00	51.58	30	12	40.00
F_3	NARC	SPP	24.85	50	8	16.00	21.35	50	17	34.00	31.00	50	11	22.00
F_4	NARC	SPP	21.53	105	35	33.33	21.15	100	64	64.00	16.21	70	18	25.71
F_4	FJ	SPP	19.99	105	42	40.00	20.85	100	83	83.00	24.45	70	31	44.29
F_4	FJ	BM	19.99	60	6	10.00	20.85	60	18	30.00	24.45	60	0	0.00
F_4	NARC	BM	21.53	60	7	11.67	21.15	60	5	8.33	16.21	60	27	45.00
F_4	FJ	SSD	19.99	60	20	33.33	20.85	60	37	61.67	24.45	60	8	13.33
F_4	NARC	SSD	21.53	60	38	63.33	21.15	60	26	43.33	16.21	60	36	60.00
			9020/Mash 1				Mash 1/9020				9020/9012			
F_2	NARC	SPP	54.15	30	15	50.00	54.15	30	21	70.00	57.00	30	6	20.00
F_3	NARC	SPP	30.50	50	9	18.00	30.50	50	6	12.00	25.95	50	13	26.00
F_4	NARC	SPP	19.05	55	23	41.82	19.05	55	36	65.45	17.60	115	4	3.48
F_4	FJ	SPP	21.57	55	31	56.66	21.57	55	16	29.09	24.19	115	1	0.87
F_4	FJ	BM	21.57	60	19	31.67	21.57	60	38	63.33	24.19	60	33	55.00
F_4	NARC	BM	19.05	60	40	66.67	19.05	60	30	50.00	17.60	60	31	51.67
F_4	FJ	SSD	21.57	60	26	43.33	21.57	60	31	51.67	24.19	60	23	38.33
F_4	NARC	SSD	19.05	60	40	66.67	19.05	60	34	56.67	17.60	60	41	68.33
			9012/9020				9025/9026							
F_2	NARC	SPP	57.00	30	6	20.00	37.10	30	18	60.00				
F_3	NARC	SPP	25.95	50	2	4.00	15.25	50	36	72.00				
F_4	NARC	SPP	17.60	55	27	49.09	22.58	100	26	26.00				
F_4	FJ	SPP	24.19	55	46	83.64	19.05	100	52	52.00				
F_4	FJ	BM	24.19	60	12	20.00	19.05	60	8	13.33				
F_4	NARC	BM	17.60	60	9	15.00	22.58	60	6	10.00				
F_4	FJ	SSD	24.19	60	3	5.00	19.05	60	32	53.33				
F_4	NARC	SSD	17.60	60	39	65.00	22.58	60	9	15.00				

progenies were better over MP in SPP at FJ and were followed by 40% in F_2, in 12 plants at NARC (Table 4.1.6). Similar results were observed in Mash 3/Mash 1 for this trait at both the locations. However, in this hybrid the range in SPP was high at both the locations (Fig. 4.1.35a and b).

The results obtained in cross Mash 3/9026 revealed high range in all the breeding methods at NARC as compared to FJ (Fig. 4.1.36a and b). Table 4.1.6 shows that the 70% plants have longer pods than MP in F_2. However, SSD produced 35.0% and 31.7% plants over mid parents for this trait at FJ and NARC, respectively.

Figure 4.1.37a and b (Mash 1/9026) revealed similar results at both the locations with minor differences. The ranges in all the breeding methods in this cross were slightly increased towards either side of mid parent especially in SPP. The hybrid 9012/9025 also indicated narrow range segregation in BM and SSD, whereas, at FJ, Single Plant Progenies produced 8 progenies in the range of 25 – 30 cm 5 pods length (Fig. 4.1.38a and b). In F_2, all the plants were better over MP in SPP while 53.3% plants were superior in F_4 in SSD (Table 4.1.6). In cross 9020/Mash 3, similar results were observed at FJ for SPP as in cross 9012/9025 (Fig. 4.1.39a). However, BM and SSD produced two plants each which were better for pod length at NARC (Fig. 4.1.39b).

Single Seed Descent was better in the hybrid 9020/Mash 1 for pods length at FJ, while at NARC (Fig. 4.1.40b). All the breeding methods produced better range as compared to Fig. 4.1.40a and b. Table 4.1.6 revealed that all the breeding methods were close in performance for pod length. Bulk method produced 83.3% better segregants over MP at NARC while SSD gave 81.7% better at NARC.

Results observed in reciprocal cross (Mash 1/9020), revealed low range in all the breeding methods. Bulk Method at both the locations and SSD at FJ produced desirable transgressive segregation for this trait (Fig. 4.1.41a and b). Table 4.1.6 confirmed the results presented in Figures. However, SPP failed to produced any plant with >25cm 5 pod length at both the locations. While concluding the performance of this hybrid after reviewing the Table and Figures, it could be suggested that all the methods were equal in performance at both the locations, while direct cross (9020/Mash1) was better for superior segregations for pod length. Although little variance of pod length is a characteristic of blackgram but from this hybrid progenies with long pods could be expected.

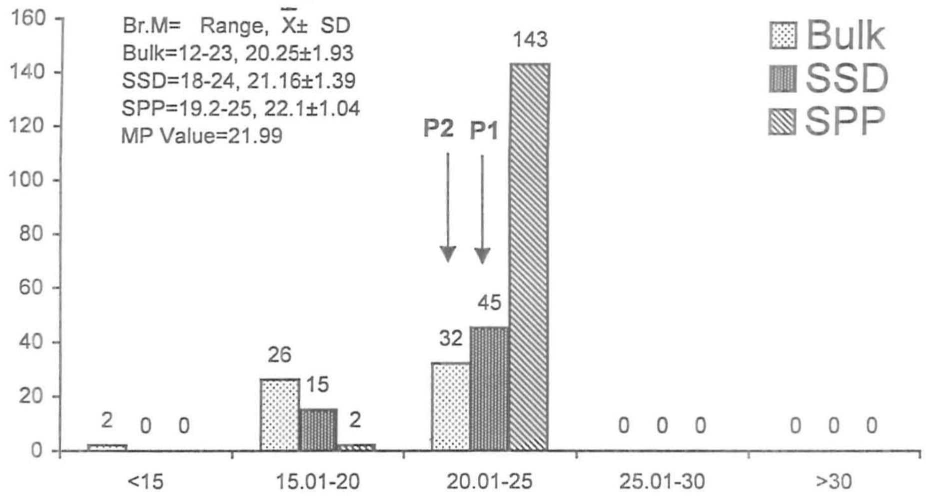


Fig. 4.1.34a. Comparison of three breeding methods for 5 pods length in 9025/Mash 1 of blackgram at FJ

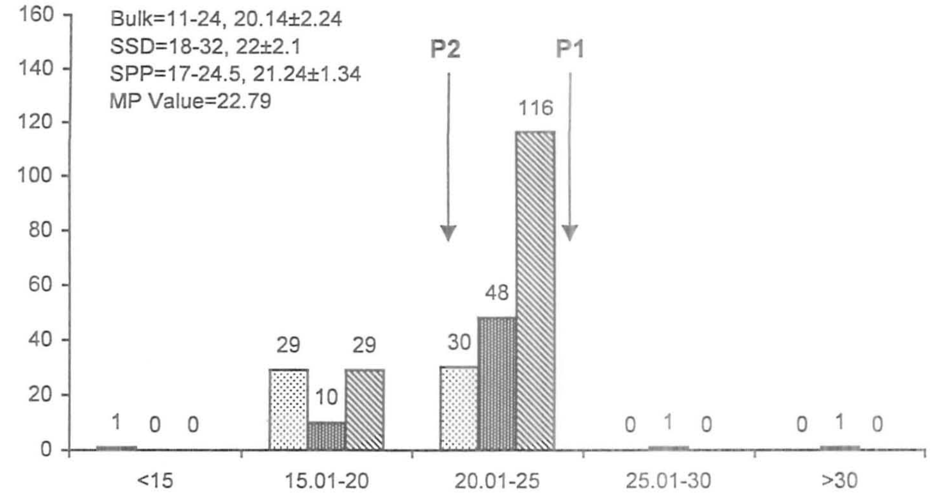


Fig. 4.1.34b. Comparison of three breeding methods for 5 pods length in 9025/Mash 1 of blackgram at NARC

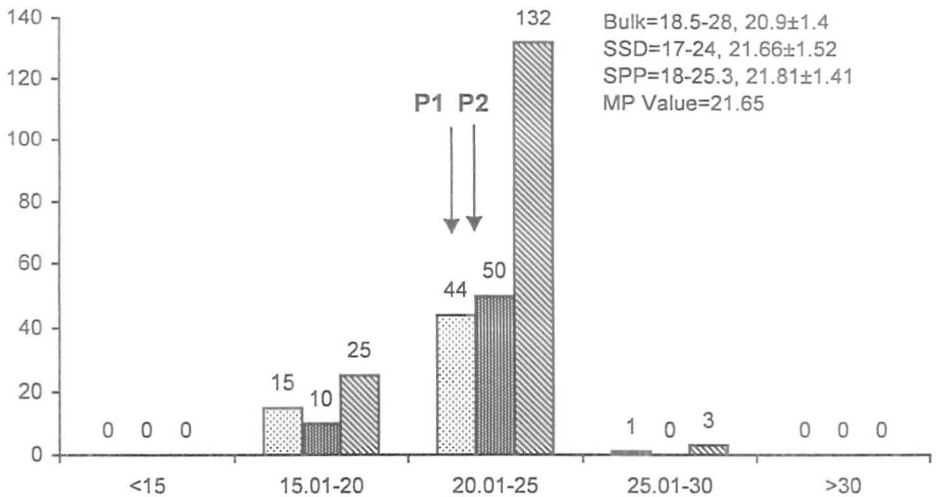


Fig. 4.1.35a. Comparison of three breeding methods for 5 pods length in Mash 3/Mash 1 of blackgram at FJ

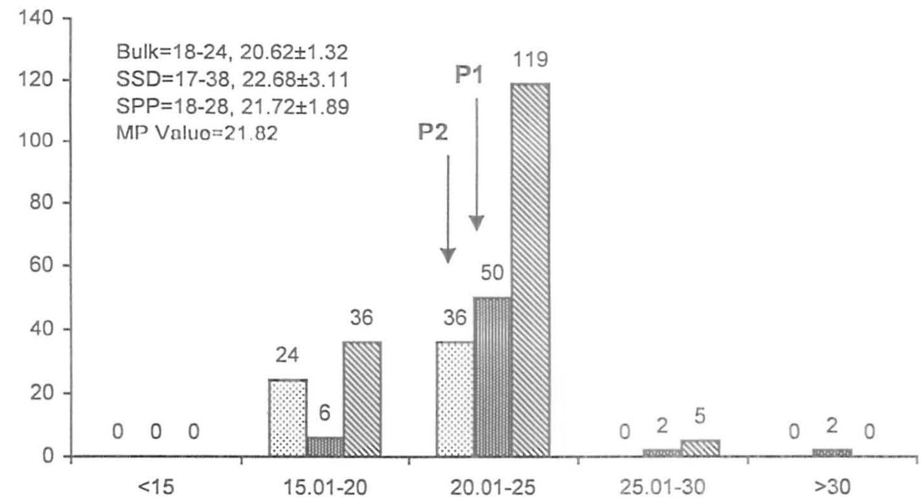


Fig. 4.1.35b. Comparison of three breeding methods for 5 pods length in Mash 3/Mash 1 of blackgram at NARC

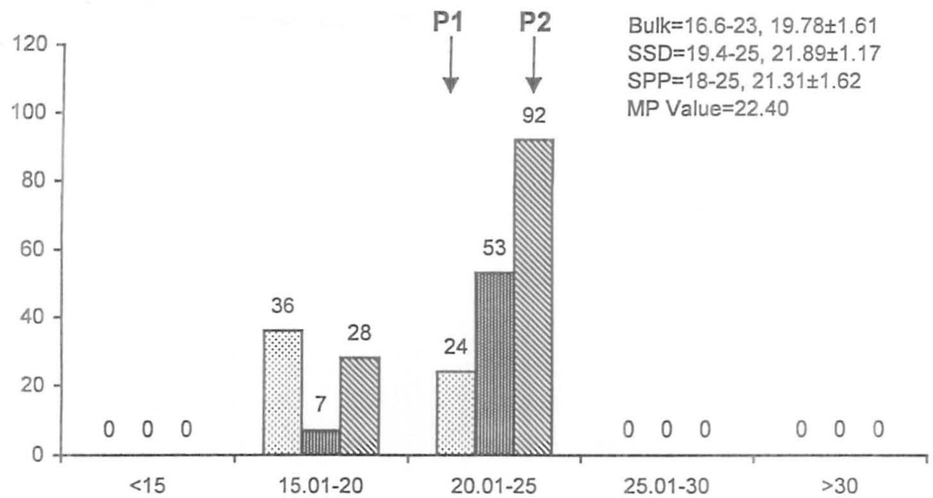


Fig. 4.1.36a. Comparison of three breeding methods for 5 pods length in Mash 3/9026 of blackgram at FJ

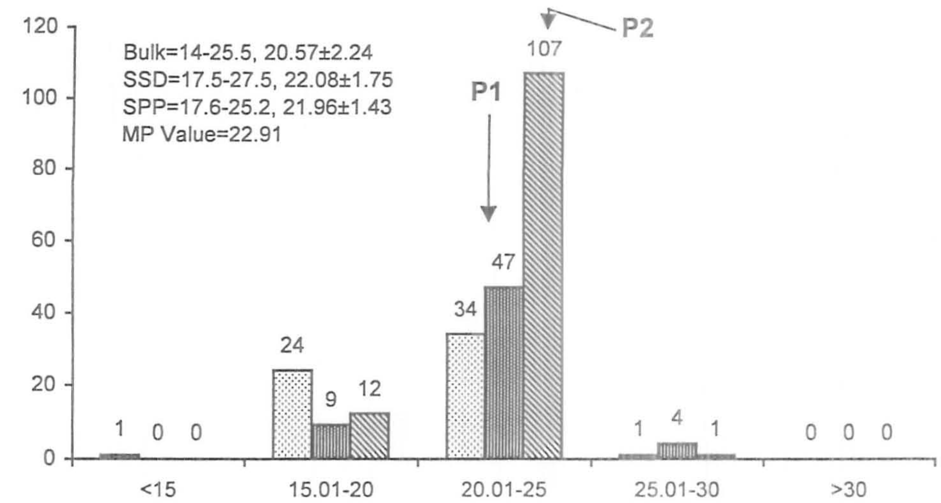


Fig. 4.1.36b. Comparison of three breeding methods for 5 pods length in Mash 3/9026 of blackgram at NARC

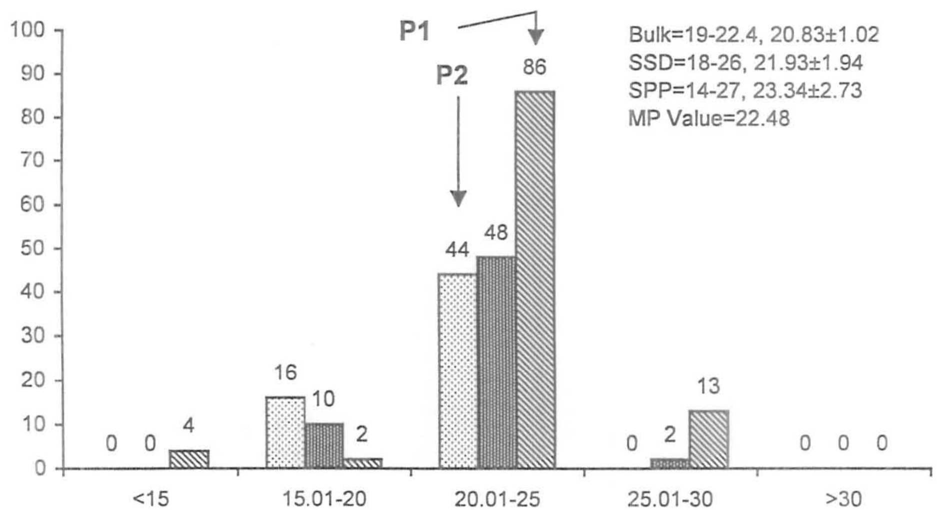


Fig. 4.1.37a. Comparison of three breeding methods for 5 pods length in Mash 1/9026 of blackgram at FJ

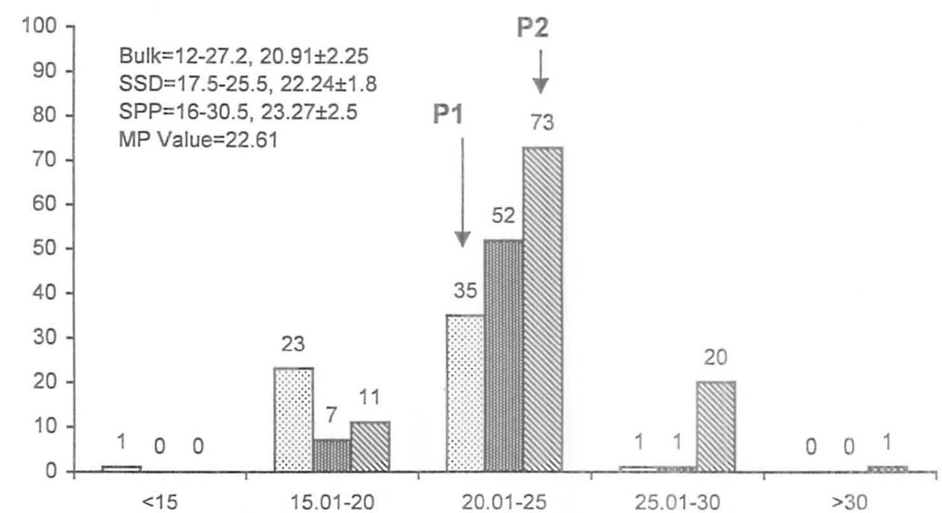


Fig. 4.1.37b. Comparison of three breeding methods for 5 pods length in Mash 1/9026 of blackgram at NARC

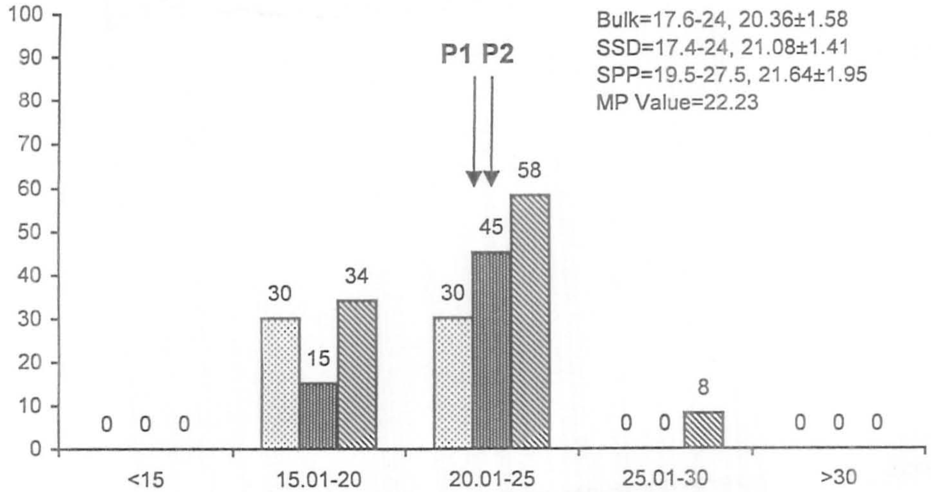


Fig. 4.1.38a. Comparison of three breeding methods for 5 pods length in 9012/9025 of blackgram at FJ

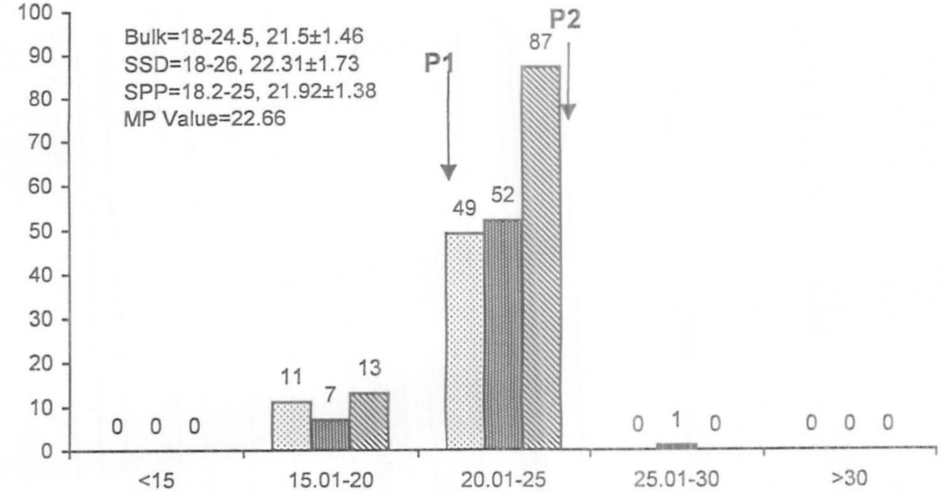


Fig. 41.38b. Comparison of three breeding methods for 5 pods length in 9012/9025 of blackgram at NARC

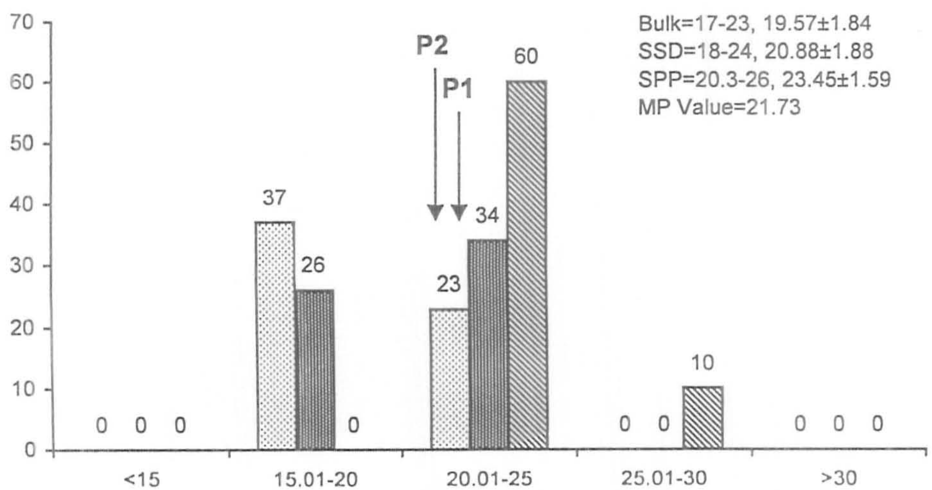


Fig. 4.1.39a. Comparison of three breeding methods for 5 pods length in 9020/Mash 3 of blackgram at FJ

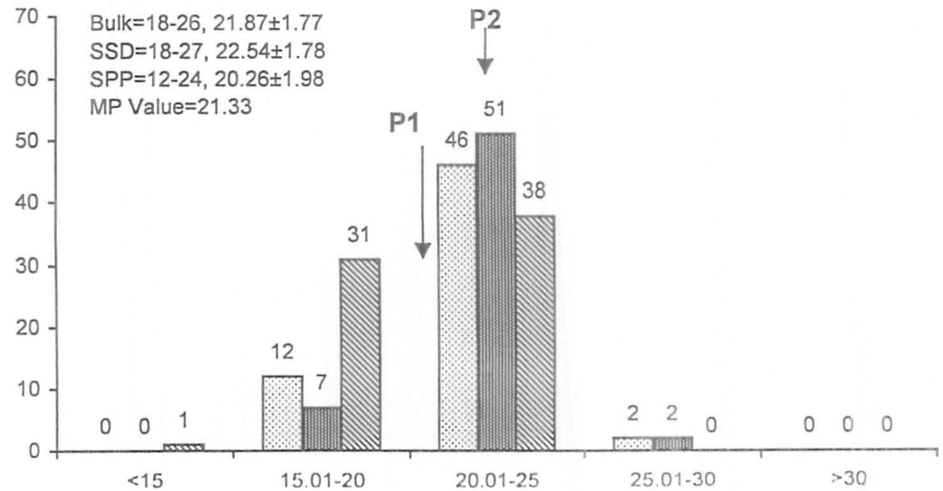


Fig. 4.1.39b. Comparison of three breeding methods for 5 pods length in 9020/Mash 3 of blackgram at NARC

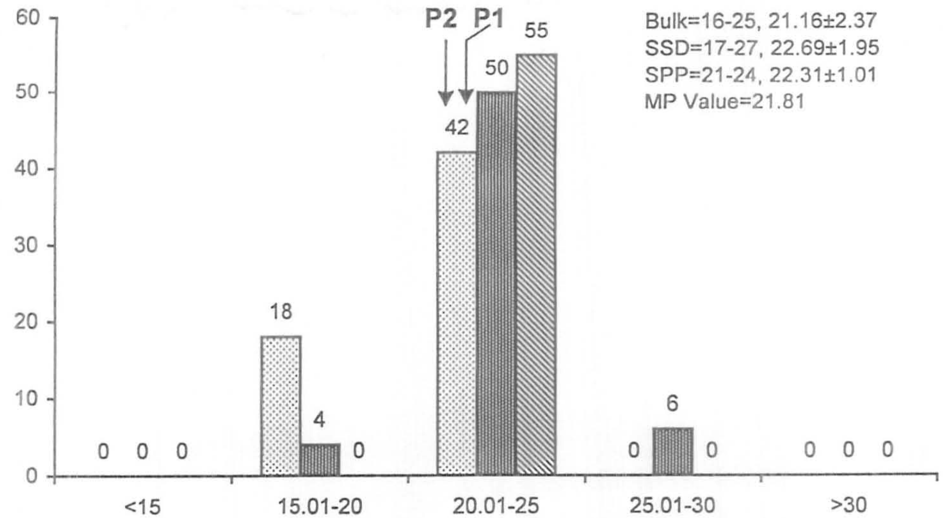


Fig. 4.1.40a. Comparison of three breeding methods for 5 pods length in 9020/Mash 1 of blackgram at FJ

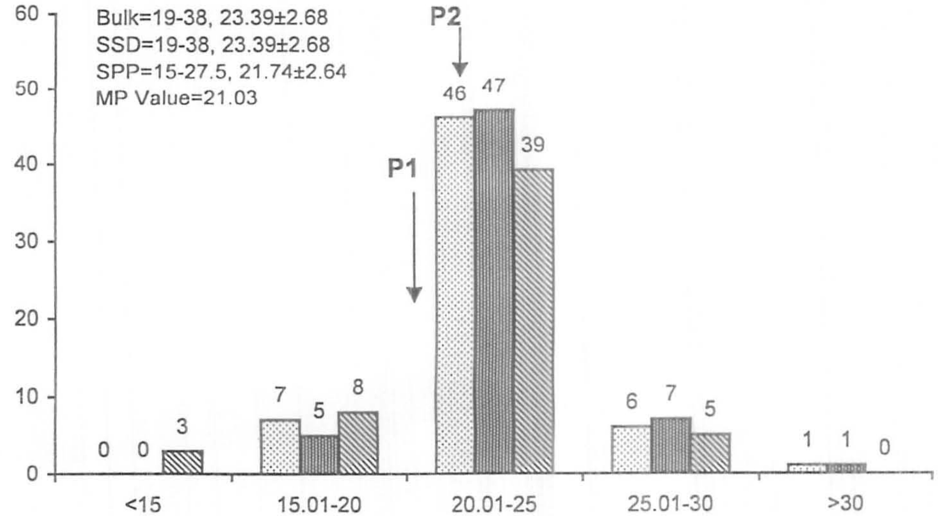


Fig. 4.1.40b. Comparison of three breeding methods for 5 pods length in 9020/Mash 1 of blackgram at NARC

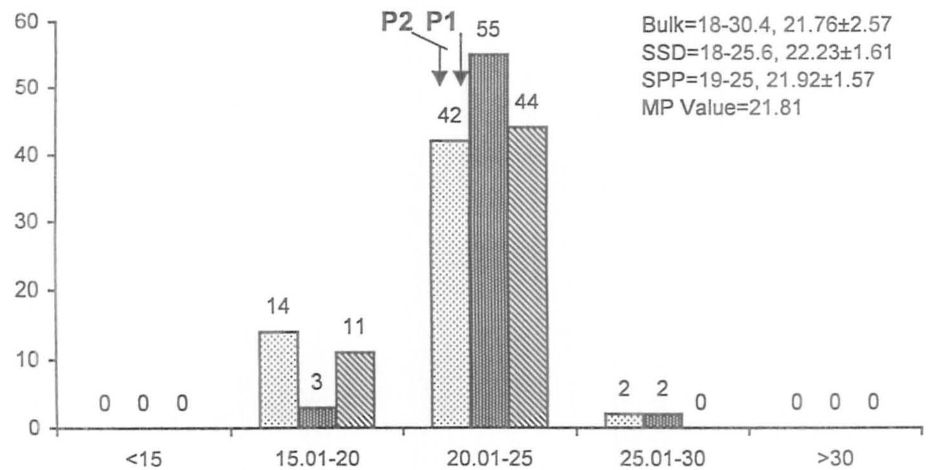


Fig. 4.1.41a. Comparison of three breeding methods for 5 pods length in Mash 1/9020 of blackgram at FJ

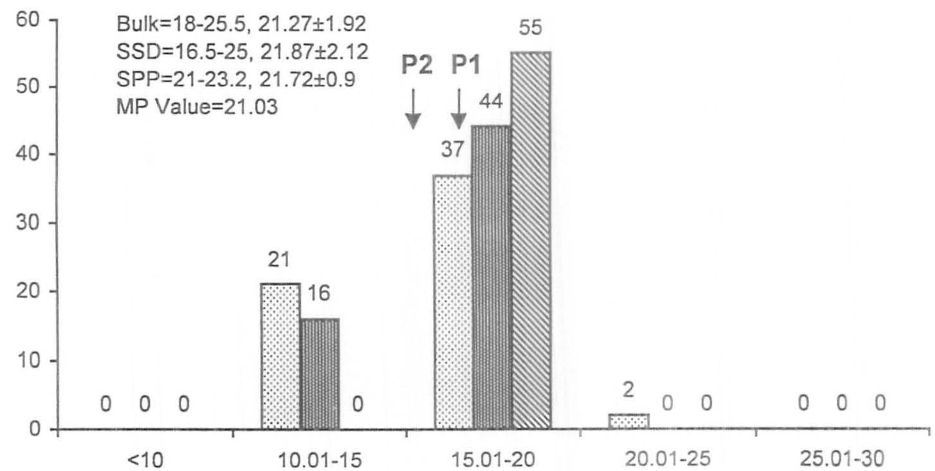


Fig. 4.1.41b. Comparison of three breeding methods for 5 pods length in Mash 1/9020 of blackgram at NARC

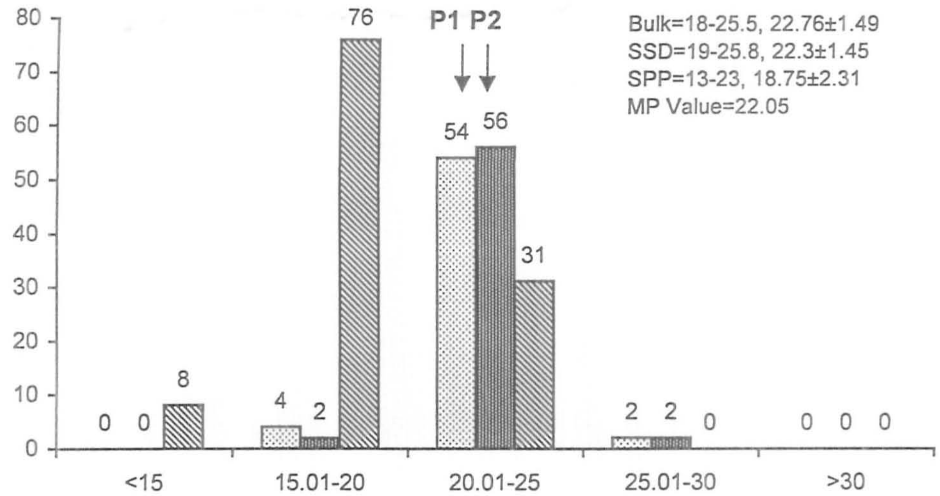


Fig. 4.1.42a. Comparison of three breeding methods for 5 pods length in 9020/9012 of blackgram at FJ

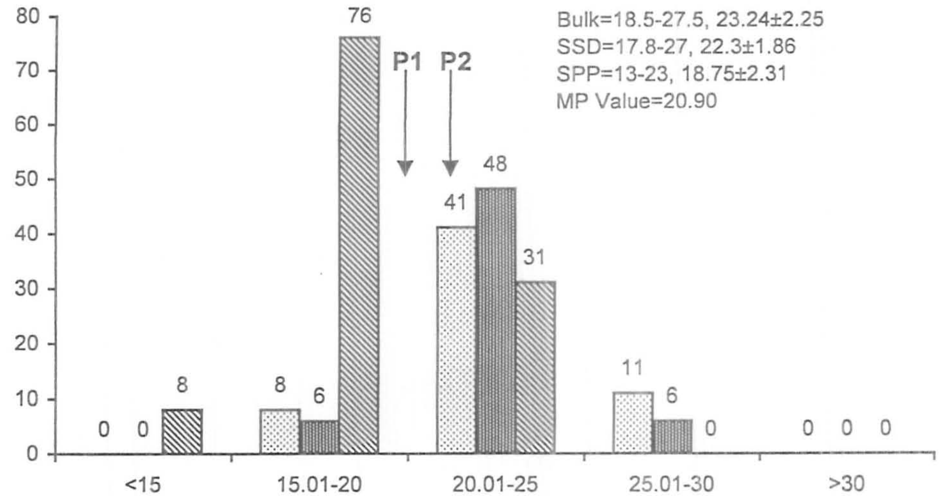


Fig. 4.1.42b. Comparison of three breeding methods for 5 pods length in 9020/9012 of blackgram at NARC

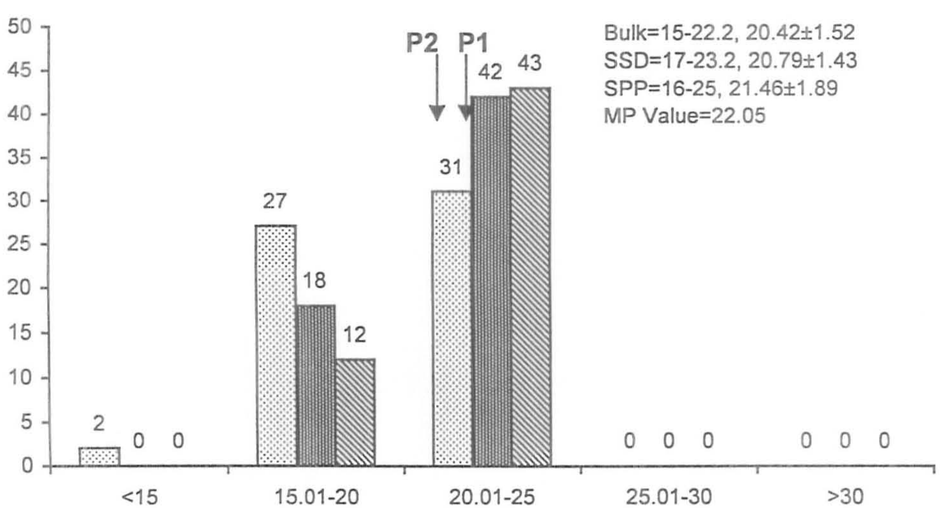


Fig. 4.1.43a. Comparison of three breeding methods for 5 pods length in 9012/9020 of blackgram at FJ

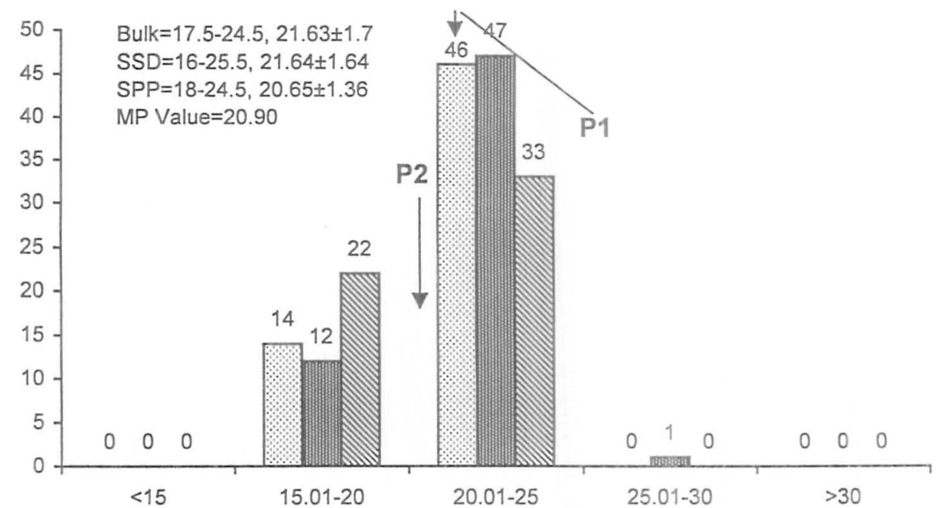


Fig. 4.1.43b. Comparison of three breeding methods for 5 pods length in 9012/9020 of blackgram at NARC

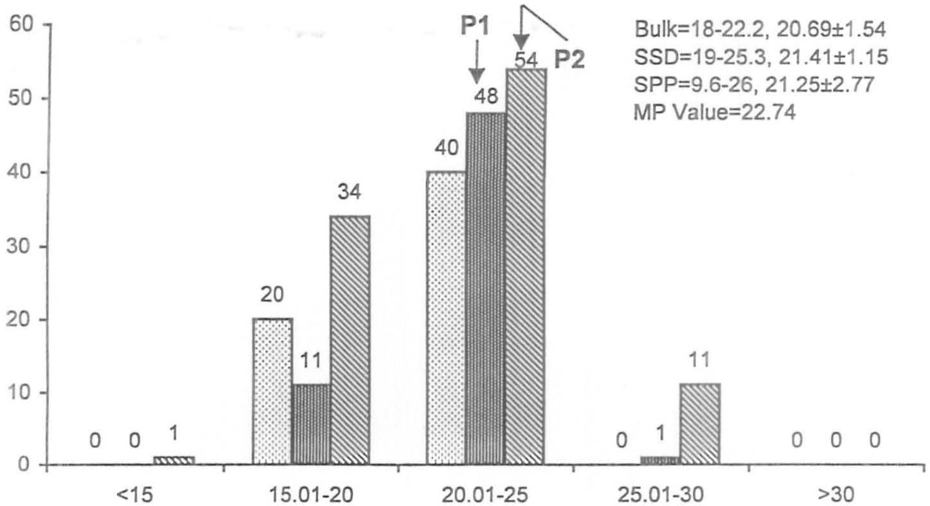


Fig. 4.1.44a. Comparison of three breeding methods for 5 pods length in 9025/9026 of blackgram at FJ

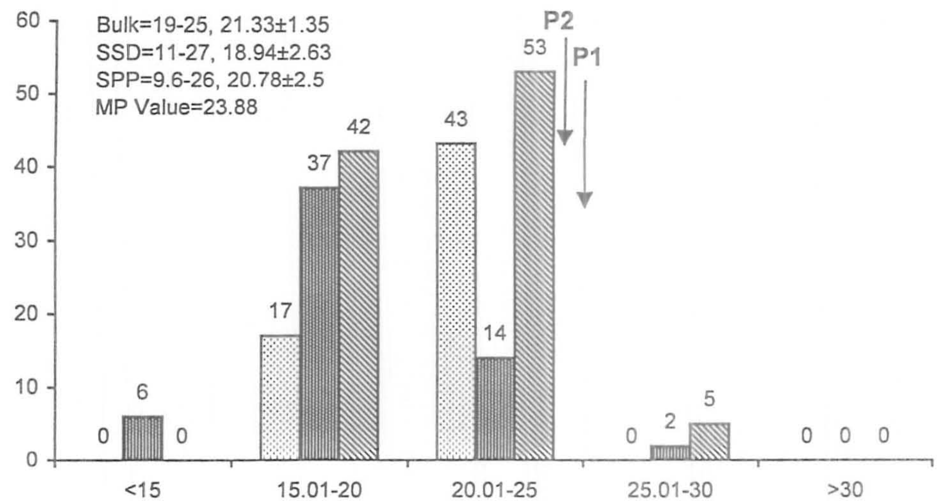


Fig. 4.1.44b. Comparison of three breeding methods for 5 pods length in 9025/9026 of blackgram at NARC

Table 4.1.6: Number of plants and their percentage over mid parents value in 5 pods length plant^{-1} in 11 crosses at two locations.

Gen.	Location	Br. M.	M P Value	No. of sample collected	No. of plants over MP	%age over MP	M P Value	No. of sample collected	No. of plants over MP	%age over MP	M P Value	No. of sample collected	No. of plants over MP	%age over MP
			9025/Mash 1				Mash 3/Mash 1				Mash 3/9026			
F_2	NARC	SPP	22.55	30	12	40.00	22.43	30	24	80.00	21.69	30	21	70.00
F_3	NARC	SPP	22.83	50	6	12.00	21.87	50	21	42.00	21.42	50	20	40.00
F_4	NARC	SPP	22.79	145	22	15.17	21.82	160	80	50.00	22.91	120	32	26.67
F_4	FJ	SPP	21.99	145	95	65.52	21.65	160	93	58.13	22.40	120	21	17.50
F_4	FJ	BM	21.99	60	9	15.00	21.65	60	13	21.67	22.40	60	8	13.33
F_4	NARC	BM	22.79	60	7	11.67	21.82	60	9	15.00	22.91	60	9	15.00
F_4	FJ	SSD	21.99	60	19	31.67	21.65	60	33	55.00	22.40	60	19	31.67
F_4	NARC	SSD	22.79	60	16	26.67	21.82	60	39	65.00	22.91	60	21	35.00
			Mash 1/9026				9012/9025				9020/Mash 3			
F_2	NARC	SPP	22.86	30	18	60.00	22.24	30	30	100.0	22.78	30	12	40.00
F_3	NARC	SPP	23.15	50	24	48.00	21.68	50	8	16.00	20.37	50	34	68.00
F_4	NARC	SPP	22.61	105	66	62.86	22.66	100	28	28.00	21.33	70	19	27.14
F_4	FJ	SPP	22.48	105	89	84.76	22.23	100	30	30.00	21.73	70	49	70.00
F_4	FJ	BM	22.48	60	0	0.00	22.23	60	8	13.33	21.73	60	8	13.33
F_4	NARC	BM	22.61	60	11	18.33	22.66	60	15	25.00	21.33	60	38	63.33
F_4	FJ	SSD	22.48	60	22	36.67	22.23	60	8	13.33	21.73	60	22	36.67
F_4	NARC	SSD	22.61	60	31	51.67	22.66	60	32	53.33	21.33	60	44	73.33
			9020/Mash 1				Mash 1/9020				9020/9012			
F_2	NARC	SPP	23.95	30	15	50.00	23.95	30	15	50.00	23.64	30	18	60.00
F_3	NARC	SPP	22.10	50	8	16.00	22.10	50	19	38.00	20.95	50	39	78.00
F_4	NARC	SPP	21.03	55	30	54.55	21.03	55	27	49.09	20.90	115	29	25.22
F_4	FJ	SPP	21.81	55	44	80.00	21.81	55	35	63.64	22.05	115	8	6.96
F_4	FJ	BM	21.81	60	28	46.67	21.81	60	26	43.33	22.05	60	41	68.33
F_4	NARC	BM	21.03	60	50	83.33	21.03	60	28	46.67	20.90	60	51	85.00
F_4	FJ	SSD	21.81	60	43	71.67	21.81	60	36	60.00	22.05	60	30	50.00
F_4	NARC	SSD	21.03	60	49	81.67	21.03	60	38	63.33	20.90	60	50	83.33
			9012/9020				9025/9026							
F_2	NARC	SPP	23.64	30	9	30.00	21.81	30	24	80.00				
F_3	NARC	SPP	20.95	50	20	40.00	22.38	50	8	16.00				
F_4	NARC	SPP	20.90	55	30	54.55	23.88	100	14	14.00				
F_4	FJ	SPP	22.05	55	29	52.73	22.74	100	30	30.00				
F_4	FJ	BM	22.05	60	8	13.33	22.74	60	0	0.00				
F_4	NARC	BM	20.90	60	42	70.00	23.88	60	2	3.33				
F_4	FJ	SSD	22.05	60	4	6.67	22.74	60	6	10.00				
F_4	NARC	SSD	20.90	60	47	78.33	23.88	60	3	5.00				

The hybrid 9020/9012 gave similar results at both the locations; however at NARC it produced high frequency within range of 25 – 30 cm pod length in BM and SSD (Fig. 4.1.42a and b). Table 4.1.6 revealed that 68.3% progenies were better for pods length over MP in BM at FJ, followed by SSD. It's reciprocal (9012/9020) showed that SSD produced only one plant with >25 cm pod length at NARC (Fig. 4.1.43b), whereas, 47 out of 60 plants were better in performance to mid parent in F_4 at NARC. Figure 4.1.44a and b revealed that the hybrid 9025/9026 exhibited desirable segregation in SSD and in SPP at both the locations. However, SPP gave higher and wider frequency.

4.1.5 5 Pods Seed

Like pod length, seeds pod^{-1} also play a vital role to increase grain yield in legume crops and these two traits are interrelated. The results obtained for seeds in five pods plant^{-1} in the hybrid 9025/Mash 1, tested at 2 locations for three breeding methods looking for desirable segregates (Fig. 4.1.45a and b). At FJ, all the breeding method produced plants in range of 31-35 seed pods^{-5}, although SPP gave the maximum plants (74) in this range. At NARC, SPP produced 4 plants >35 seeds pods^{-5}. Table 4.1.7 indicated that 83 plants out of 145 were superior to MP in SPP at FJ in F_4 and 32 plants were better in SSD at FJ in the same generation.

The hybrid, Mash 3/Mash 1, exhibited low range at FJ for seed pods^{-5} in all the breeding methods as compared to NARC, where more plant progenies with wider range were recorded (Fig. 4.1.46a and b). Table 4.1.7 reveals 101 out of 160 plants better than MP in SPP at FJ in F_4 generation and it was followed by 46 plants out 50 in F_3 at NARC.

The results observed in hybrid Mash 3/9026, showed low range in all the breeding methods, at FJ as compared to NARC (Fig. 4.1.47a and b). At FJ, all the breeding methods failed to produced any plant with >35 seeds pods^{-5} plant^{-1} while at NARC, Single Plant Progenies produced one progeny with more than 35 seeds 5 pod plant^{-1}. Single Plant Progenies produced 67% better plants progenies over MP at NARC in F_4 and was followed by 66% better plants in F_3 over MP also at NARC (Table 4.1.7).

Figures 4.1.48a and b represent cross Mash 1/9026 that reveal similarity in all the breeding methods at both the locations. However, SSD and SPP exhibited slightly better magnitude with desirable segregations at NARC. Seventy-eight percent (39 out of 50 plant progenies) were better than MP in F_3 and it was followed by 65.71% (69 out of 105

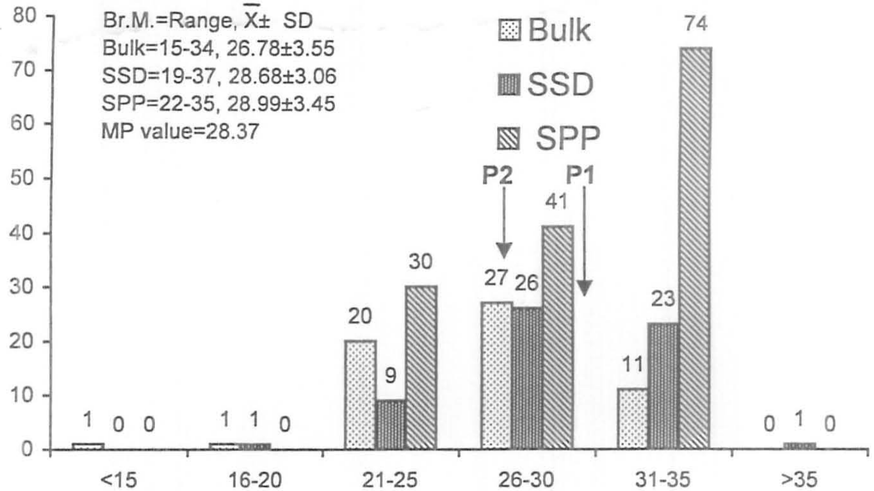


Fig. 4.1.45a. Comparison of three breeding methods for 5 pods seeds in 9025/Mash 1 of blackgram at FJ

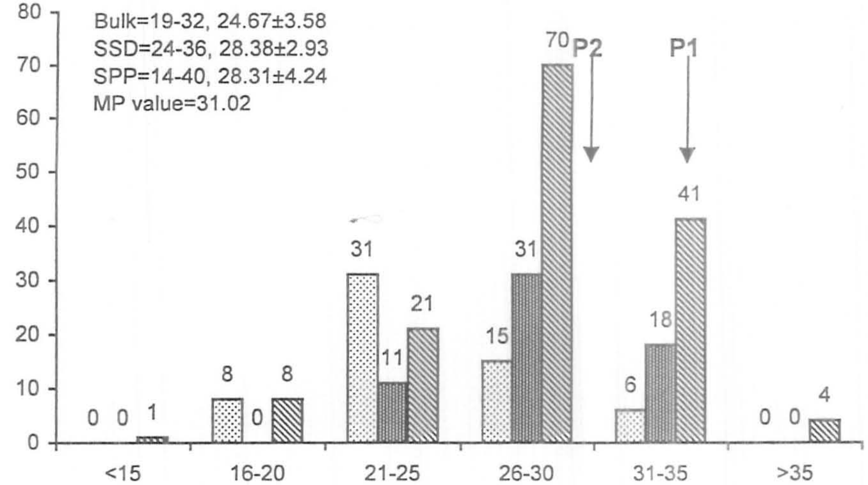


Fig. 4.1.45b. Comparison of three breeding methods for 5 pods seeds in 9025/Mash 1 of blackgram at NARC

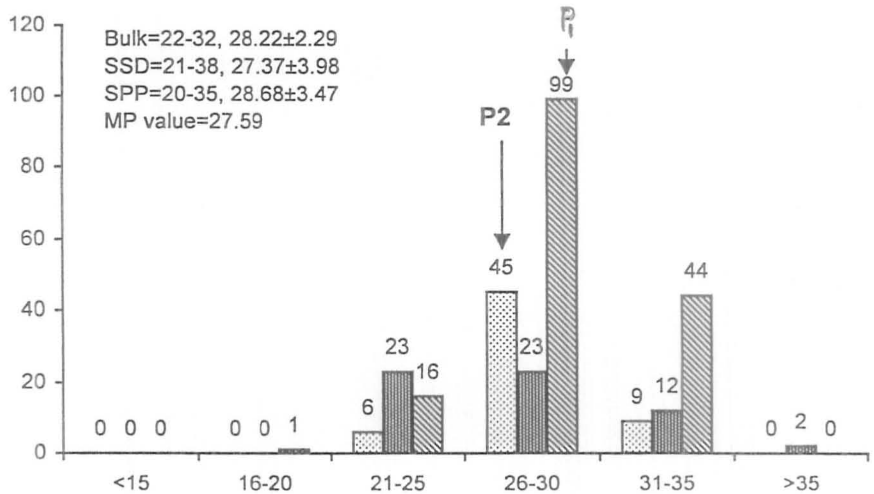


Fig. 4.1.46a. Comparison of three breeding methods for 5 pods seeds in Mash 3/Mash 1 of blackgram at FJ

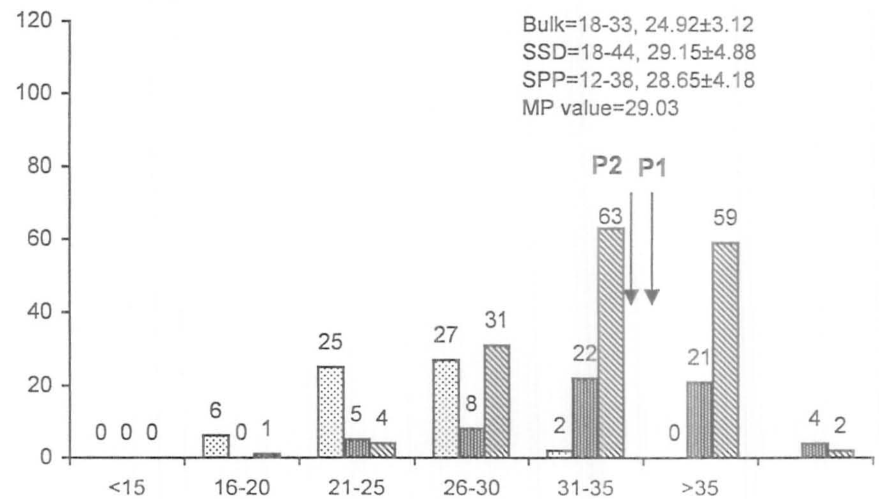


Fig. 4.1.46b. Comparison of three breeding methods for 5 pods seeds in Mash 3/Mash 1 of blackgram at NARC

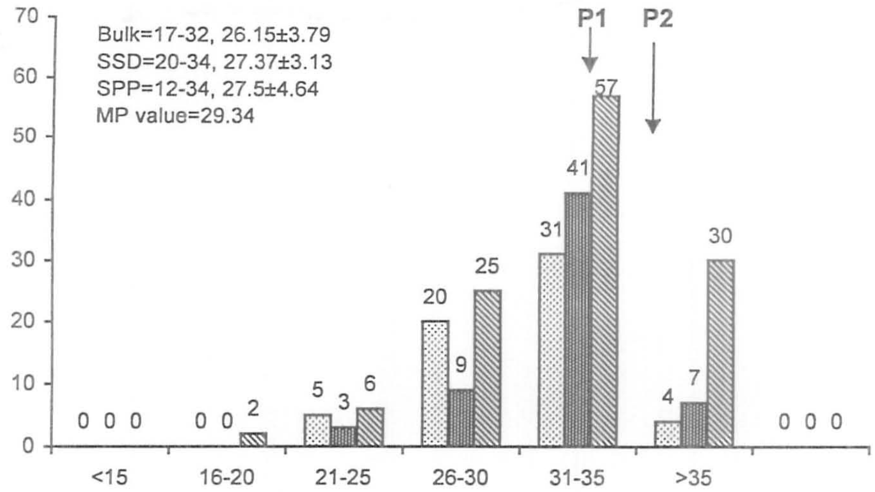


Fig. 4.1.47a. Comparison of three breeding methods for 5 pods seeds in Mash 3/9026 of blackgram at FJ

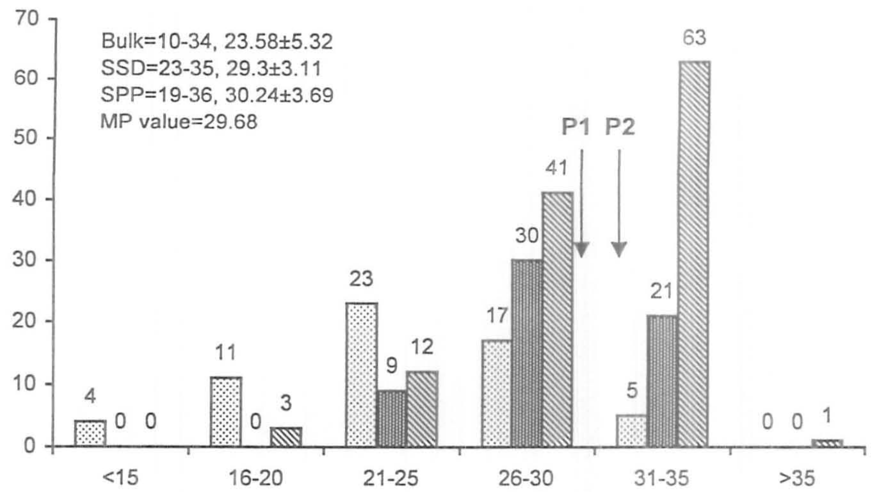


Fig. 4.1.47b. Comparison of three breeding methods for 5 pods seeds in Mash 3/9026 of blackgram at NARC

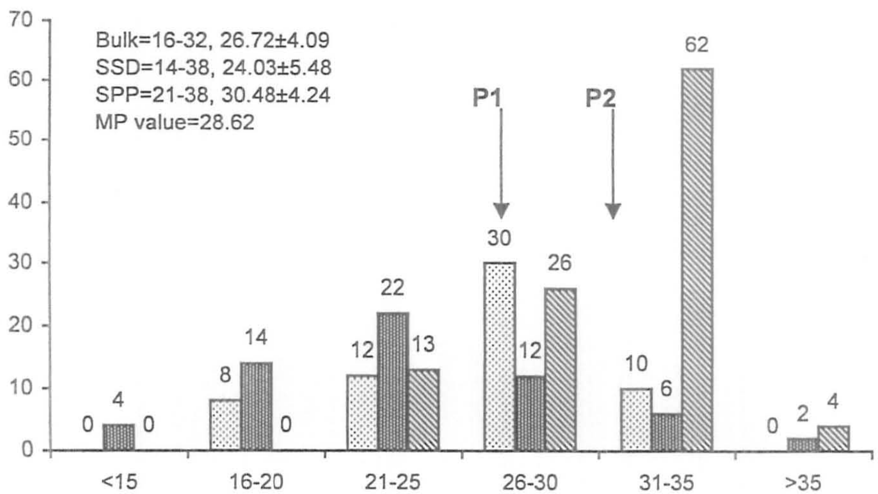


Fig. 4.1.48a. Comparison of three breeding methods for 5 pods seeds in Mash 1/9026 of blackgram at FJ

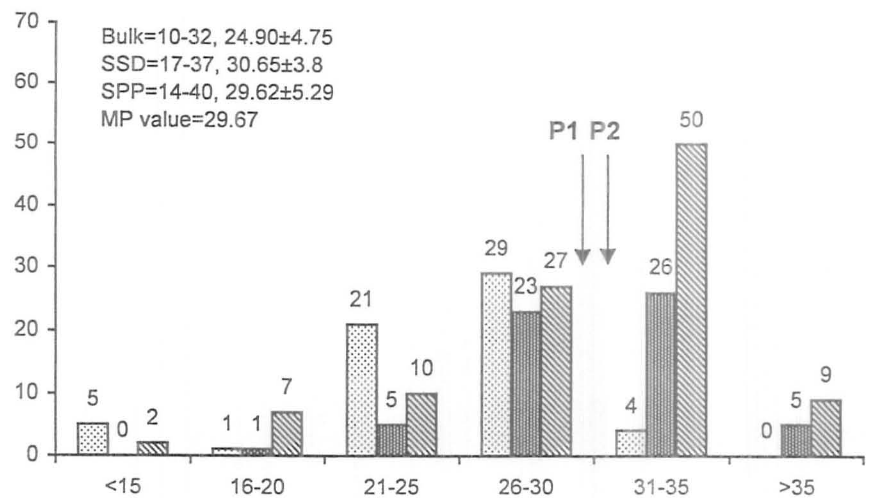


Fig. 4.1.48b. Comparison of three breeding methods for 5 pods seeds in Mash 1/9026 of blackgram at NARC

plants progenies) which were better for this trait in SPP at FJ in F_4 generation (Table 4.1.7).

Hybrid 9012/9025 revealed similar results for seeds pods^{-5} plant^{-1} in SSD and SPP at both the locations; however high frequencies were observed at NARC (Fig. 4.1.49a and b). Bulk Method failed to produce any plant with >30 seed five pod plant^{-1} at FJ but at NARC it produced 5 plants with >30 seed pods^{-5} plant^{-1}. Table 4.1.7 showed the relevancy of results with graphical representation. In cross 9020/Mash 3, SPP exhibited high range for this character at FJ while at NARC Single Seed Descent excelled the other two breeding methods (Fig. 4.1.50a and b). Eighty-one percent plants were better than MP in F_4 for this trait and in F_3, 78% plants were superior over MP at NARC.

The hybrid 9020/Mash 1, gave desirable transgressive segregation in all the breeding methods at both the locations (Fig. 4.1.51a and b). However, high range was observed for this trait at NARC in all the breeding methods indicating the scope of selection for this important trait. Table 4.1.7 revealed that maximum plant (43 progenies out of 60) in BM at NARC and 42 out of 60 in SSD at NARC, were better in this trait in F_4. The hybrid Mash 1/9020 also gave similar results at both the locations (Fig. 4.1.52a and b). However, at FJ this hybrid was unable to produce any plant with >35 seeds pods^{-5} plant^{-1} but at NARC only few plants were available. Maximum plant progenies were better over MP in SSD at both the locations (Table 4.1.7).

The hybrid 9020/9012 and its reciprocal (9012/9020) produced almost similar results at both the locations (Fig. 4.1.53a & b and 4.1.54a & b). At Fateh Jang, SSD produced 4 plants with high seed pods^{-5} plant^{-1} and its reciprocal produced 6 plants with >35 seeds pods^{-5} plant^{-1} in SPP. Table 4.1.7 revealed that BM and SSD at both the locations produced high percentage over MP for this trait.

Figures 4.1.55a and b for cross 9025/9026 exhibited limited transgressive segregations in all the breeding methods for this trait at both the locations. Single Plant Progenies produced 7 and 4 progenies which produced >35 seed pods^{-5} plant^{-1} at both the location, respectively. Table 4.1.7 indicated 40% better plant progenies for this trait over MP in F_2 while 32% and 31.7% were observed superior over MP in F_4 in SPP and SSD at FJ, respectively.

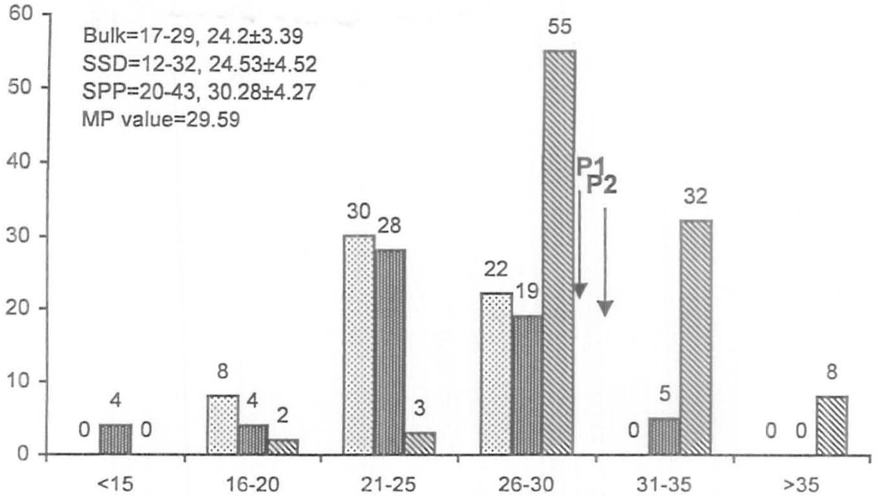


Fig. 4.1.49a. Comparison of three breeding methods for 5 pods seeds in 9012/9025 of blackgram at FJ

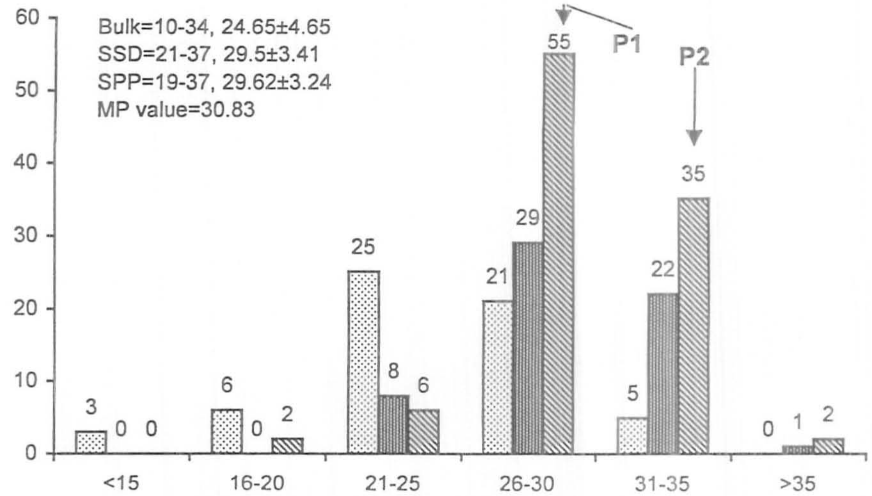


Fig. 4.1.49b. Comparison of three breeding methods for 5 pods seeds in 9012/9025 of blackgram at NARC

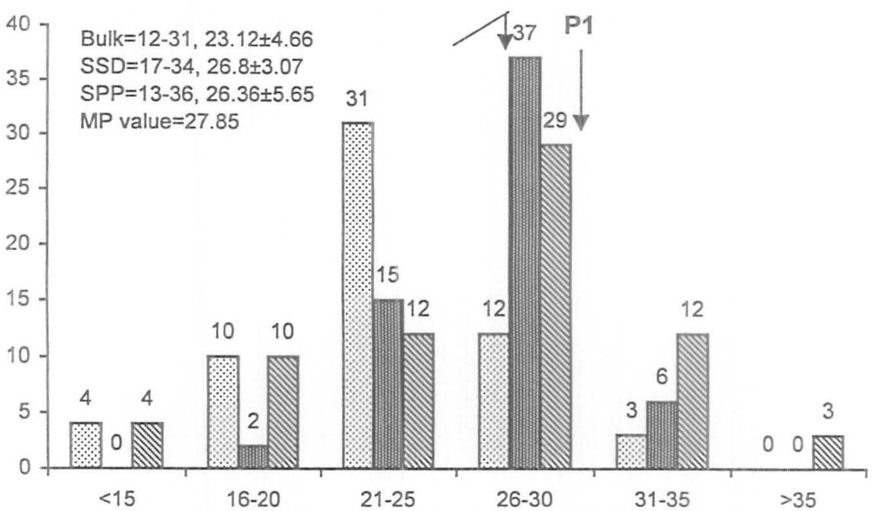


Fig. 4.1.50a. Comparison of three breeding methods for 5 pods seeds in 9020/Mash 3 of blackgram at FJ

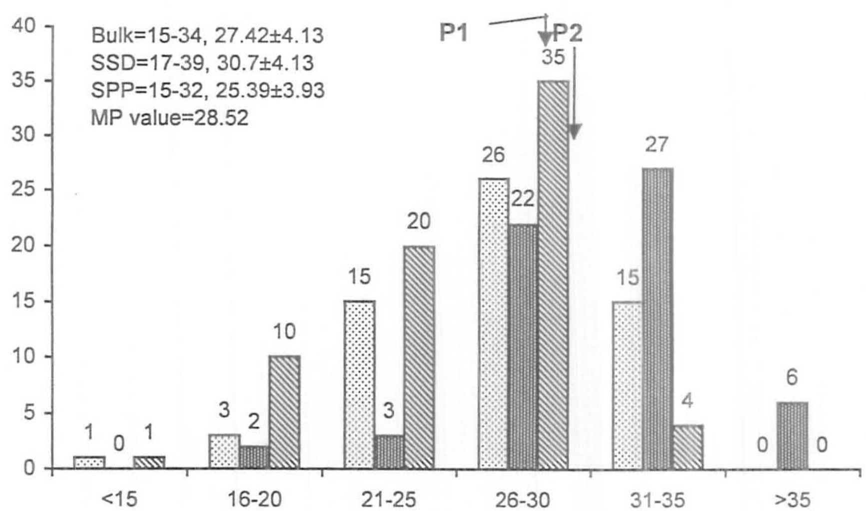


Fig. 4.1.50b. Comparison of three breeding methods for 5 pods seeds in 9020/Mash 3 of blackgram at NARC

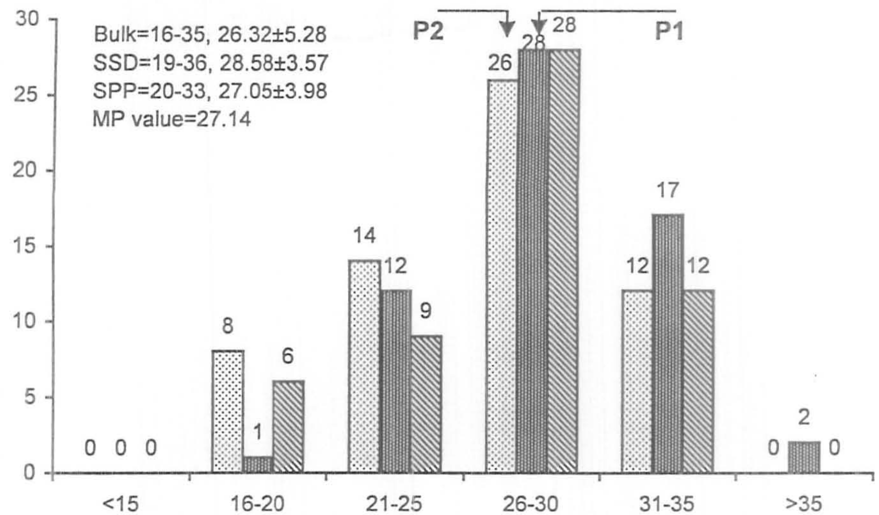


Fig. 4.1.51a. Comparison of three breeding methods for 5 pods seeds in 9020/Mash 1 of blackgram at FJ

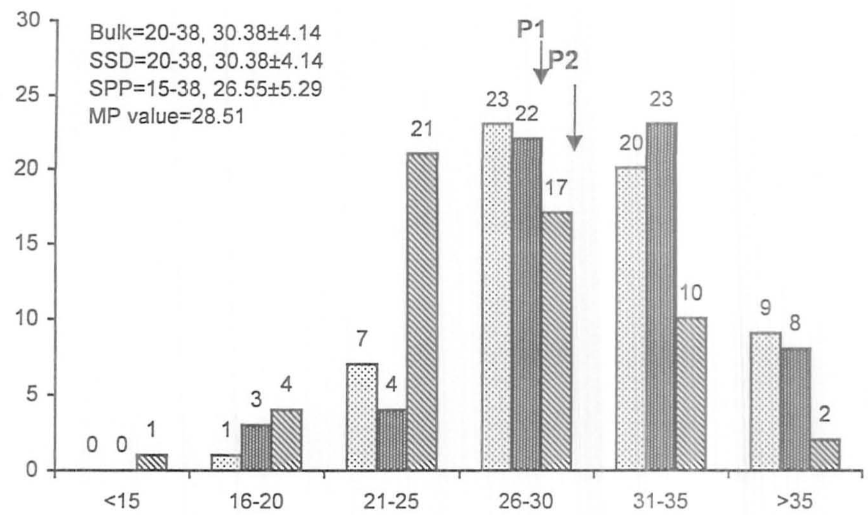


Fig. 4.1.51b. Comparison of three breeding methods for 5 pods seeds in 9020/Mash 1 of blackgram at NARC

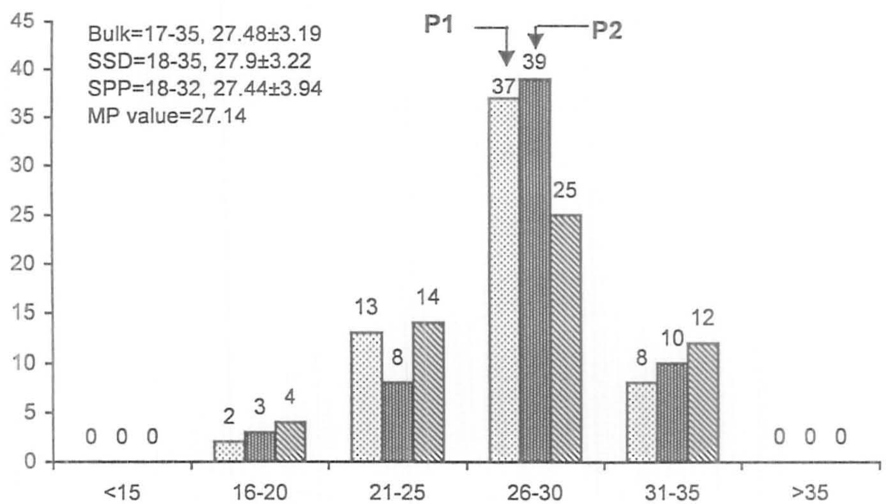


Fig. 4.1.52a. Comparison of three breeding methods for 5 pods seeds in Mash 1/9020 of blackgram at FJ

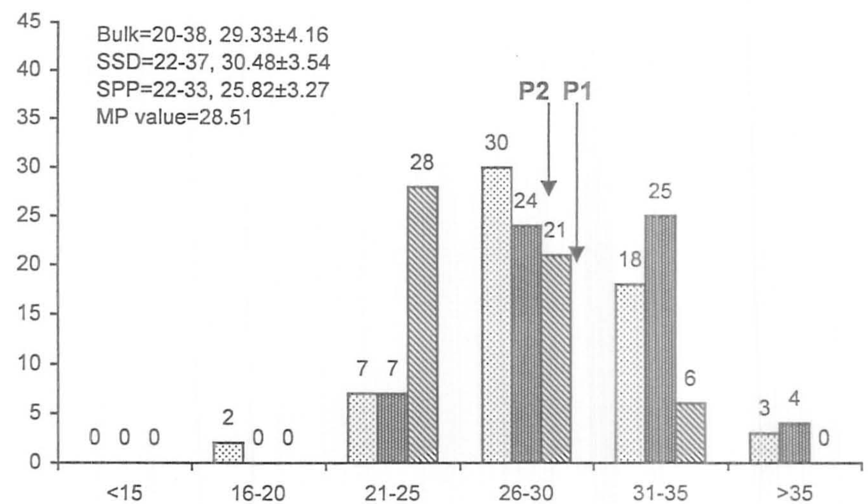


Fig. 4.1.52b. Comparison of three breeding methods for 5 pods seeds in Mash 1/9020 of blackgram at NARC

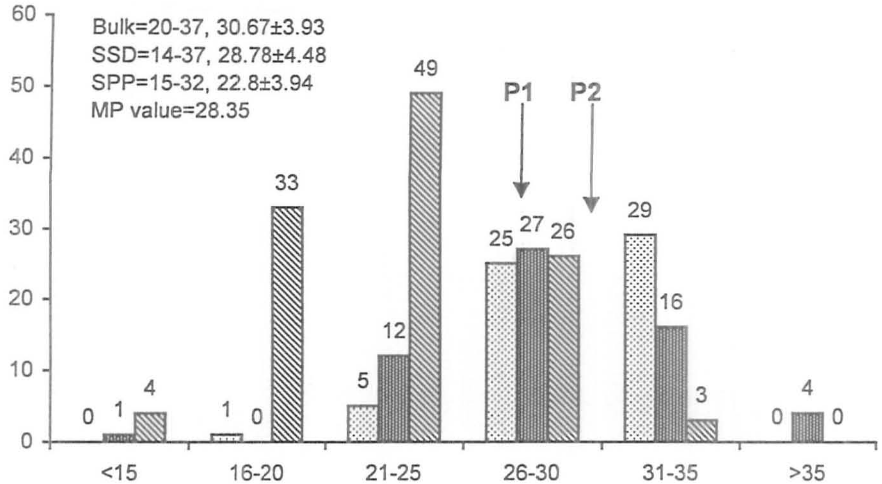


Fig. 4.1.53a. Comparison of three breeding methods for 5 pods seeds in 9020/9012 of blackgram at FJ

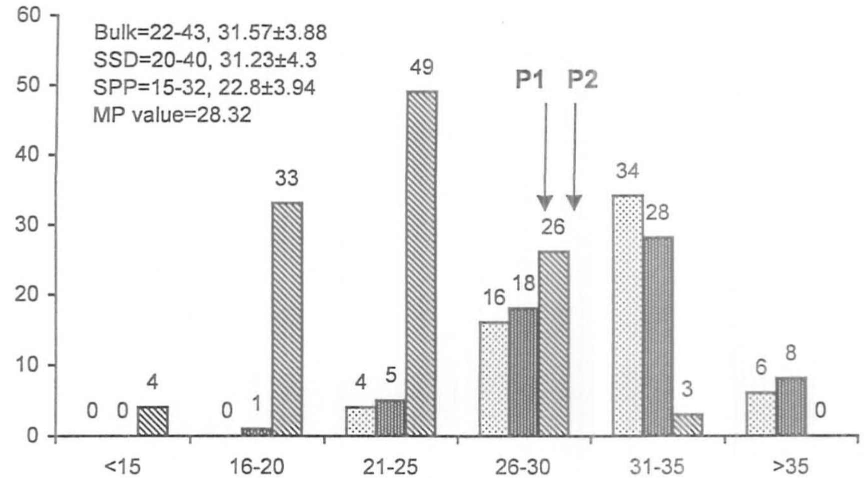


Fig. 4.1.53b. Comparison of three breeding methods for 5 pods seeds in 9020/9012 of blackgram at NARC

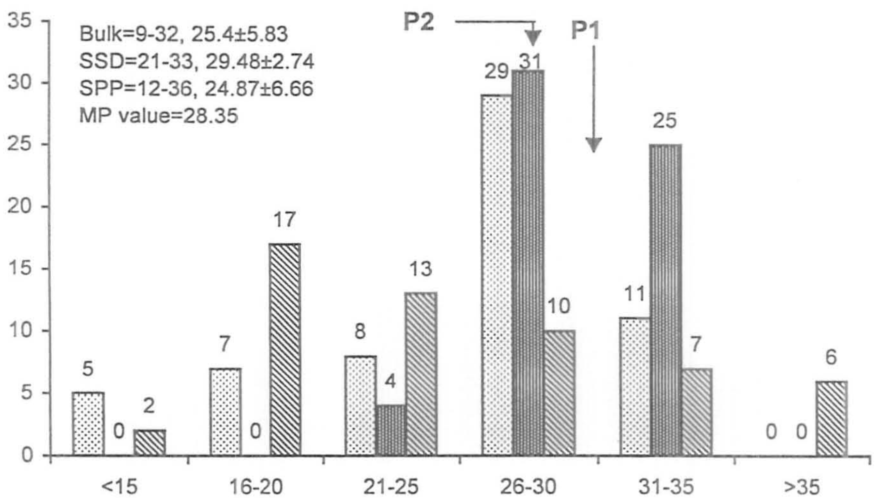


Fig. 4.1.54a. Comparison of three breeding methods for 5 pods seeds in 9012/9020 of blackgram at FJ

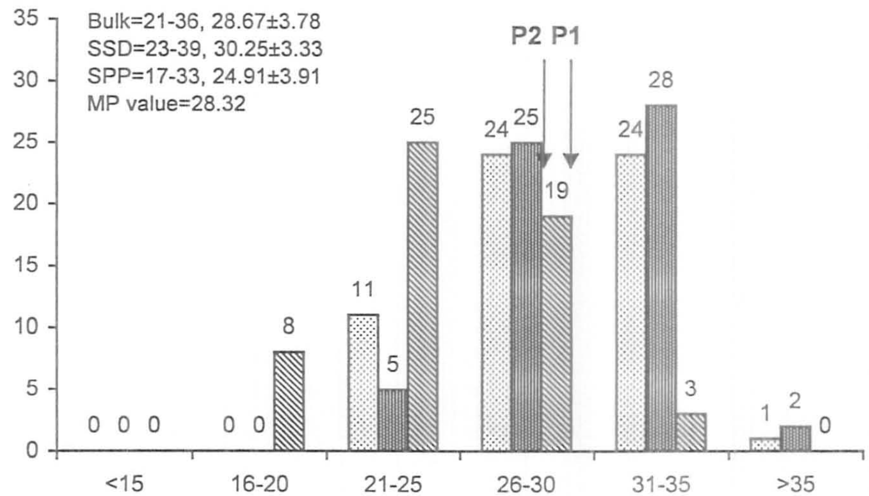


Fig. 4.1.54b. Comparison of three breeding methods for 5 pods seeds in 9012/9020 of blackgram at NARC

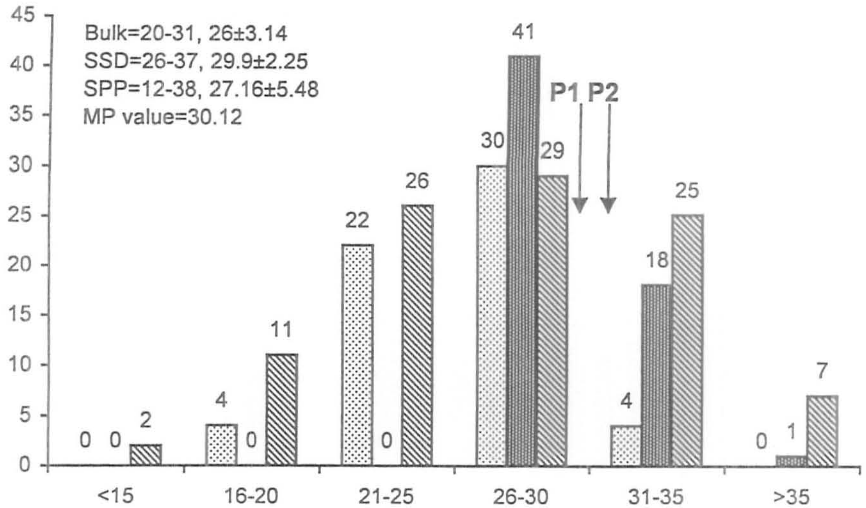


Fig. 4.1.55a. Comparison of three breeding methods for 5 pods seeds in 9025/9026 of blackgram at FJ

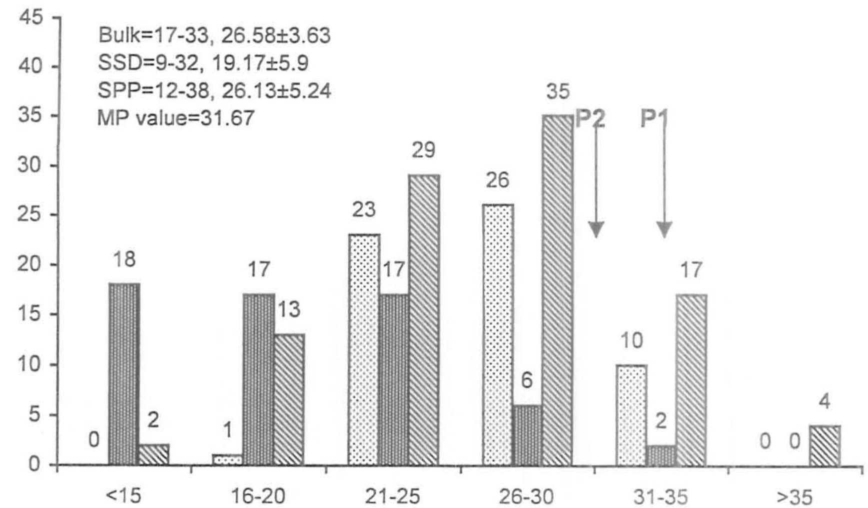


Fig. 4.1.55b. Comparison of three breeding methods for 5 pods seeds in 9025/9026 of blackgram at NARC

Table 4.1.7: Number of plants and their percentage over mid parent value in 5 pods seed in 11 crosses at two locations.

Gen.	Location	Br. M.	M P Value	No. of sample collected	No. of plants over MP	%age over MP	M P Value	No. of sample collected	No. of plants over MP	%age over MP	M P Value	No. of sample collected	No. of plants over MP	%age over MP
			9025/Mash 1				**Mash 3/Mash 1**				**Mash 3/9026**			
F_2	NARC	SPP	31.40	30	9	30.00	30.30	30	24	80.00	29.65	30	12	40.00
F_3	NARC	SPP	29.55	50	23	46.00	28.25	50	46	92.00	28.95	50	33	66.00
F_4	NARC	SPP	31.02	145	24	16.55	29.03	160	78	48.75	29.68	120	81	67.50
F_4	FJ	SPP	28.37	145	83	57.24	27.59	160	101	63.13	29.34	120	47	39.17
F_4	FJ	BM	28.37	60	19	31.67	27.59	60	41	68.33	29.34	60	14	23.33
F_4	NARC	BM	31.02	60	1	1.67	29.03	60	2	3.33	29.68	60	7	11.67
F_4	FJ	SSD	28.37	60	32	53.33	27.59	60	25	41.67	29.34	60	22	36.67
F_4	NARC	SSD	31.02	60	10	16.67	29.03	60	31	51.67	29.68	60	31	51.67
			Mash 1/9026				**9012/9025**				**9020/Mash 3**			
F_2	NARC	SPP	32.15	30	18	60.00	29.70	30	30	100.0	31.00	30	9	30.00
F_3	NARC	SPP	30.80	50	39	78.00	29.70	50	19	38.00	27.25	50	39	78.00
F_4	NARC	SPP	29.67	105	68	64.76	30.83	100	37	37.00	28.52	70	17	24.29
F_4	FJ	SPP	28.62	105	69	65.71	29.59	100	55	55.00	27.85	70	44	62.86
F_4	FJ	BM	28.62	60	21	35.00	29.59	60	0	0.00	27.85	60	31	51.67
F_4	NARC	BM	29.67	60	6	10.00	30.83	60	5	8.33	28.52	60	29	48.33
F_4	FJ	SSD	28.62	60	12	20.00	29.59	60	5	8.33	27.85	60	22	36.67
F_4	NARC	SSD	29.67	60	36	60.00	30.83	60	23	38..33	28.52	60	49	81.67
			9020/Mash 1				**Mash 1/9020**				**9020/9012**			
F_2	NARC	SPP	33.50	30	12	40.00	33.50	30	15	50.00	31.8	30	18	60.00
F_3	NARC	SPP	29.10	50	21	42.00	29.10	50	34	68.00	29.25	50	34	68.00
F_4	NARC	SPP	28.51	55	21	38.18	28.51	55	7	12.73	28.22	115	8	6.96
F_4	FJ	SPP	27.14	55	25	45.45	27.14	55	31	56.36	28.35	115	8	6.96
F_4	FJ	BM	27.14	60	29	48.33	27.14	60	31	51.67	28.35	60	46	76.67
F_4	NARC	BM	28.51	60	43	71.67	28.51	60	36	60.00	28.22	60	48	80.00
F_4	FJ	SSD	27.14	60	37	61.67	27.14	60	40	66.67	28.35	60	28	46.67
F_4	NARC	SSD	28.51	60	42	70.00	28.51	60	41	68.33	28.22	60	44	73.33
			9012/9020				**9025/9026**							
F_2	NARC	SPP	31.80	30	27	90.00	30.75	30	12	40.00				
F_3	NARC	SPP	29.25	50	24	48.00	30.25	50	8	16.00				
F_4	NARC	SPP	28.32	55	14	25.45	31.67	100	14	14.00				
F_4	FJ	SPP	28.35	55	28	50.91	30.12	100	32	32.00				
F_4	FJ	BM	28.35	60	18	30.00	30.12	60	4	6.67				
F_4	NARC	BM	28.32	60	33	55.00	31.67	60	4	6.67				
F_4	FJ	SSD	28.35	60	38	63.33	30.12	60	19	31.67				
F_4	NARC	SSD	28.32	60	42	70.00	31.67	60	1	1.67				

4.1.6 100 Seed Weight

Seed weight in any field crop plays an important role in its productivity and quality. The consumers like mostly bold seeded character in food legumes. To improve seed weight in blackgram, hybridization is important by involving bold seeded parents. One of the parent (9025) used in the present study was bold seeded with >5g/100 seed weight. Therefore, high transgressive segregation could be expected from some hybrids in the present material. The hybrid 9025/Mash 1 revealed high mean and wide range in SPP at FJ (Fig. 4.1.56a). The range was slightly reduced at NARC (Fig. 4.1.56b). The results observed at FJ were more favourable for better seed size in SPP. At NARC, none of the progeny was better than parents that indicated non-additive nature of gene action involved in this cross under NARC environmental conditions. Ninety percent plant progenies observed were better in F_2 at NARC in SPP and it was followed by 24.1% in F_4 at FJ in the same generation (Table 4.1.8).

The results observed in hybrid Mash 3/Mash 1 revealed wide range in SPP at both the locations especially at FJ, along with high mean values (Fig. 4.1.57a and b). Single Seed Descent gave plant progenies only in the range of 4.51-5.0g (15) and 5.01-5.5g (45) at FJ. The progenies observed at FJ with more than 5.5gm 100 seed weight were very important for bold seed in blackgram. It is important to note that 22 plant progenies gave more than 6.0g seed weight plant^{-1} at FJ, their retesting under wide range of environment to select the best one for seed weight coupled with good plant type and high yield potential. Table 4.1.8 indicated that 45 (75%) plant progenies in SSD were superior at FJ in F_4 and was followed by 114 out of 160 (71.25) plant progenies in SPP which were superior over MP in F_4 at FJ.

The hybrid Mash 3/9026 showed high mean value (5.20) coupled with wide range in SPP with almost normal distribution curve at FJ while at NARC quite reverse results were obtained (Fig. 4.1.58a and b). This hybrid also produced 18 plant progenies at FJ that have more than 6g 100 seed weight, their careful reevaluation in the next generation will lead to bold seeded plant selection. Bulk Method and SSD could not produce plants with more than 5.5g 100 seed weight at both the locations. Table 4.1.8 confirmed the finding presented in Figures for this cross at both the locations. However, 60.0% superior plant progenies in F_2 for 100 seed weight over MP were observed in SPP at NARC. The cross Mash 1/9026 (Fig. 4.1.59b) revealed similar results as described in Mash 3/9026 at

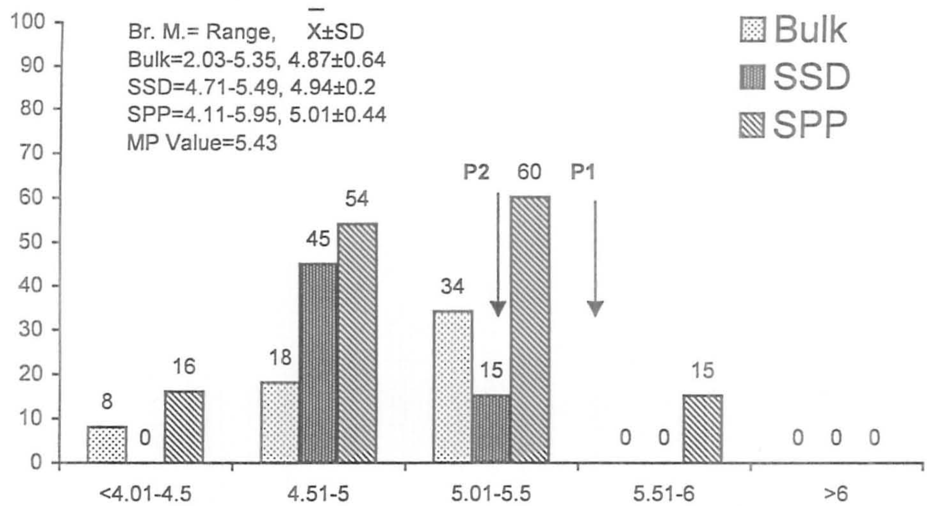


Fig. 4.1.56a. Comparison of three breeding methods for 100 seed weight plant^{-1} in 9025/Mash 1 of blackgram at FJ

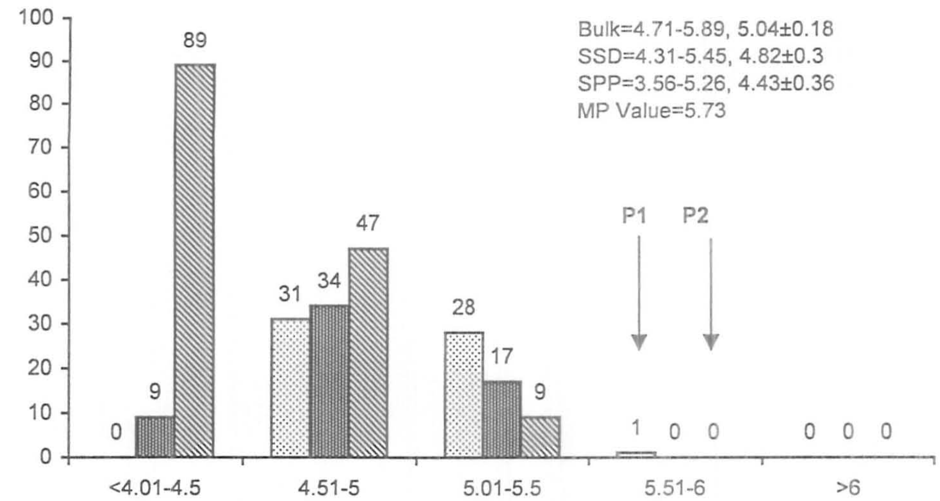


Fig. 4.1.56b.Comparison of three breeding methods for 100 seed weight plant^{-1} in 9025/Mash 1 of blackgram at NARC

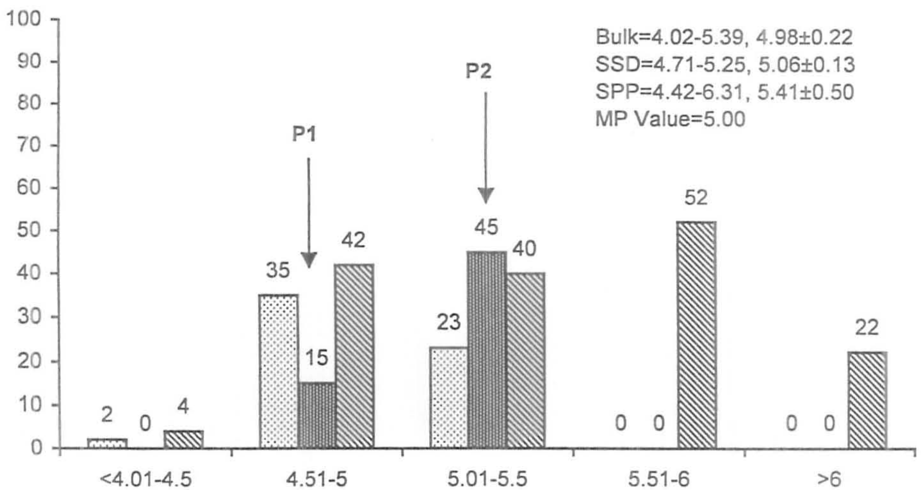


Fig. 4.1.57a. Comparison of three breeding methods for 100 seed weight plant^{-1} in Mash 3/Mash 1 of blackgram at FJ

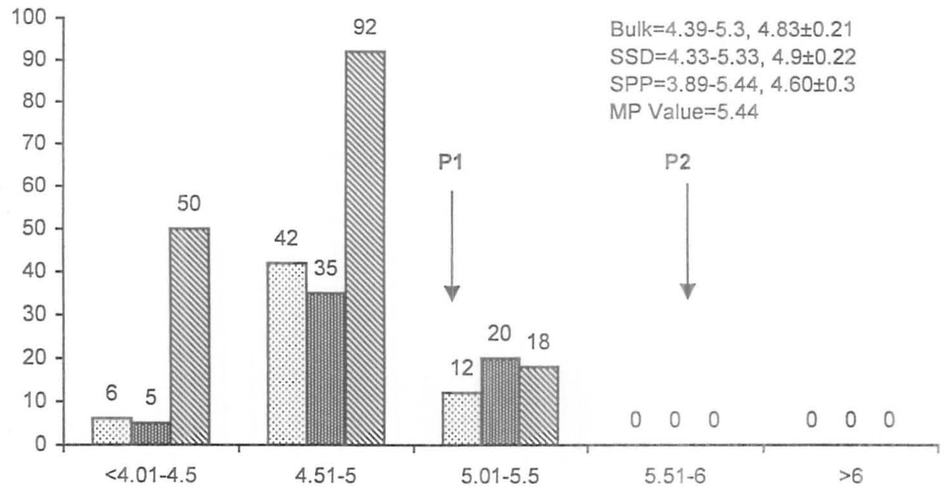


Fig. 4.1.57b. Comparison of three breeding methods for 100 seed weight plant^{-1} in Mash 3/Mash 1 of blackgram at NARC

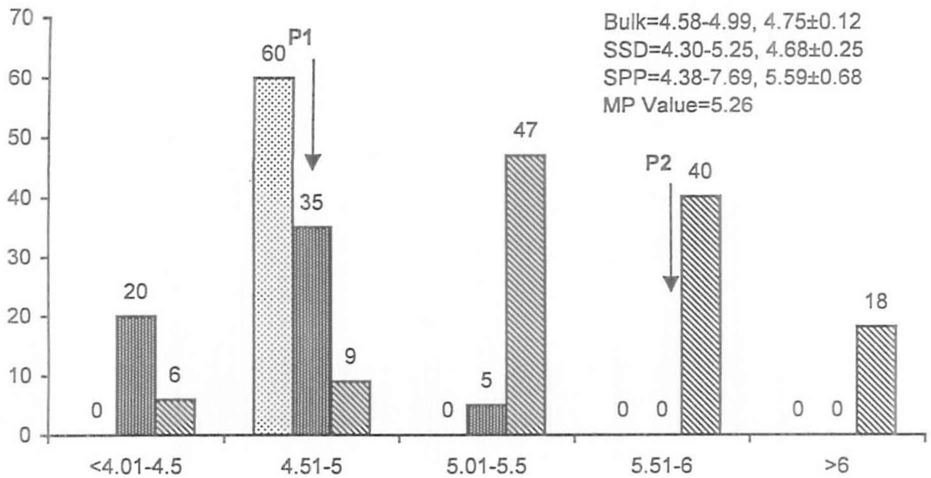


Fig. 4.1.58a. Comparison of three breeding methods for 100 seed weight plant^{-1} in Mash 3/9026 of blackgram at FJ

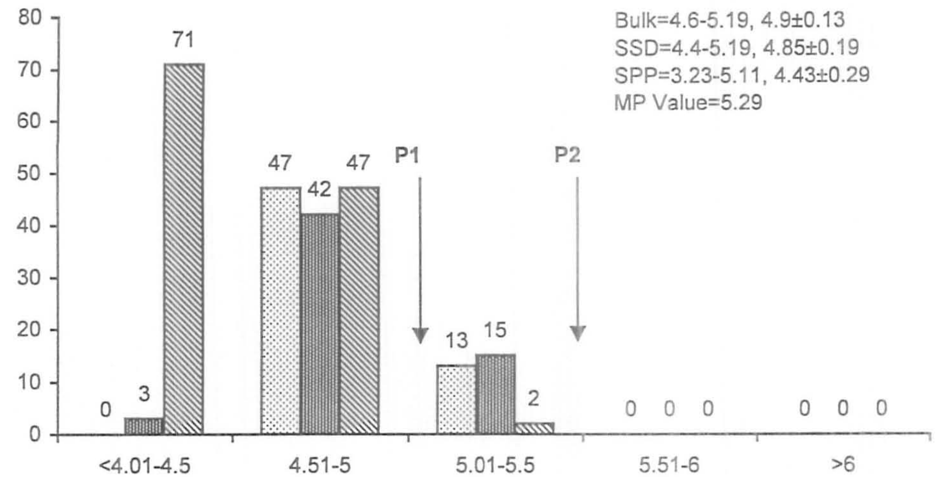


Fig. 4.1.58b. Comparison of three breeding methods for 100 seed weight plant^{-1} in Mash 3/9026 of blackgram at NARC

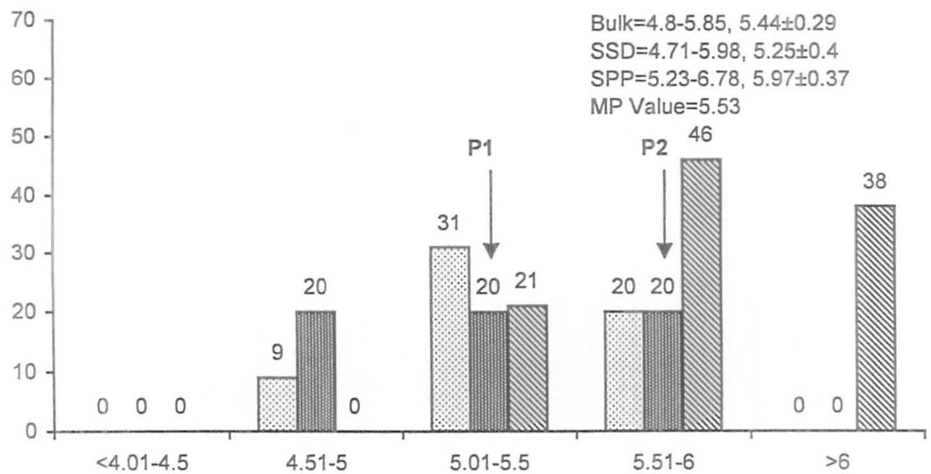


Fig. 4.1.59a. Comparison of three breeding methods for 100 seed weight plant^{-1} in Mash 1/9026 of blackgram at FJ

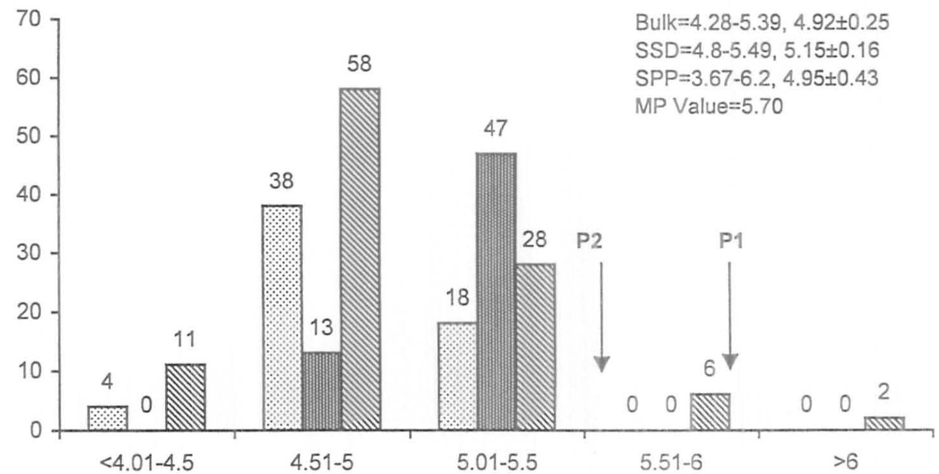


Fig. 4.1.59b. Comparison of three breeding methods for 100 seed weight plant^{-1} in Mash 1/9026 of blackgram at NARC

NARC. However, in this cross SPP also produced few plants with high 100 seed weight at NARC. Ninety percent plant progenies with better 100 seed weight were observed in F_2 at NARC in SPP (Table 4.1.8). While concluding the results of these two crosses it was observed that SPP was better breeding method for this trait. This situation suggested the involvement of non-additive gene action that cumulated in selected progenies at random.

The results observed in hybrid 9012/9025 revealed low transgressive segregation at both the locations; although few plant progenies were observed in the range of 5.5-6g 100 seed weight at NARC (Fig. 4.1.60a and b). Sixty seven percent better plant progenies in BM for the trait at FJ were observed (Table 4.1.8). The result in cross 9020/Mash 3 exhibited positive transgressive segregants at FJ, and it was observed that all the populations in all the methods exhibited higher seed weight than both the parents (Fig. 4.1.61a and b). At NARC, the progenies were not in high range i. e., >6.0g.

The hybrid 9020/Mash 1and it's reciprocal (Mash 1/9020) revealed similar results for 100 seed weight plant^{-1} at both the locations (Fig. 4.1.62a & b and 4.1.63a & b). All the breeding methods revealed segregation towards positive side of the mid parent values especially at FJ, while at NARC low frequency was observed in all the breeding methods. The results of Mash 1/9020 gave high positive range in SSD and SPP at FJ; however, at NARC only SSD produced two plant of higher 100 seed weight than mid parent value. Table 4.1.8 indicated the similar result in F_4 in all the breeding methods at both the locations. However, F_2 and F_3 produced high percentage over MP in direct and its reciprocal cross at NARC as compared to FJ.

The hybrid 9020/9012 and its reciprocal exhibited similar result as were described in previous cross and reciprocal (Fig. 4.1.64a & b and 4.1.65a & b). However, the reciprocal cross revealed that all the progenies in all the breeding methods were superior to both the parents at FJ (Fig. 4.1.65a). At NARC, all the breeding methods were unable to give any plant with more than 5.5g 100 seed weight plant^{-1}, except in BM where one plant progeny was observed. Table 4.1.8 indicated similar directions as described in Figures 4.1.65a and b for both the crosses and their reciprocal over MP in both the location. The hybrid 9020/9012 produced high range especially at FJ in SSD where 9 progenies yielded more than 6g 100 seed weight plant^{-1} (Fig. 4.1.64a). The same cross

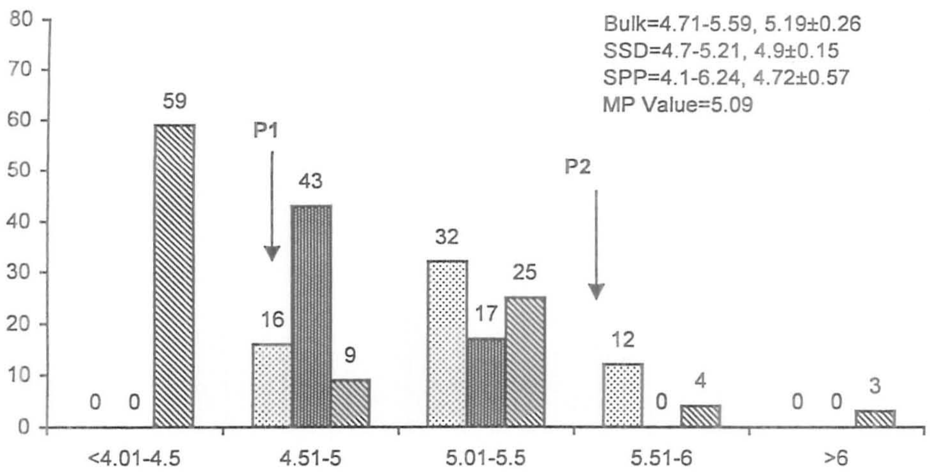


Fig. 4.1.60a. Comparison of three breeding methods for 100 seed weight plant^{-1} in 9012/9025 of blackgram at FJ

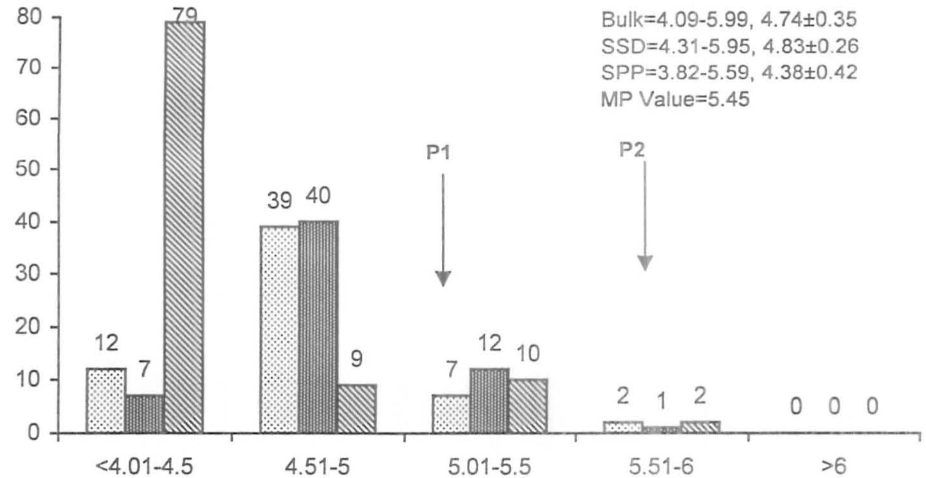


Fig. 4.1.60b. Comparison of three breeding methods for 100 seed weight plant^{-1} in 9012/9025 of blackgram at NARC

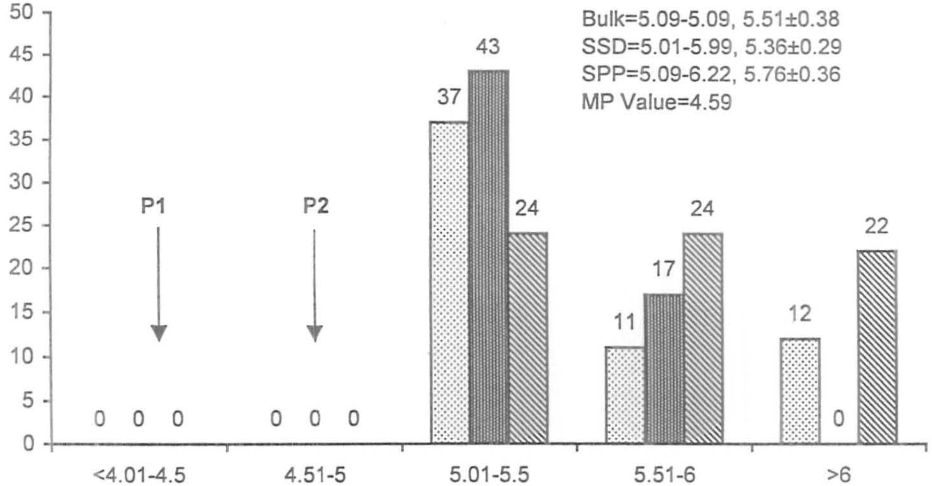


Fig. 4.1.61a. Comparison of three breeding methods for 100 seed weight plant^{-1} in 9020/Mash 3 of blackgram at FJ

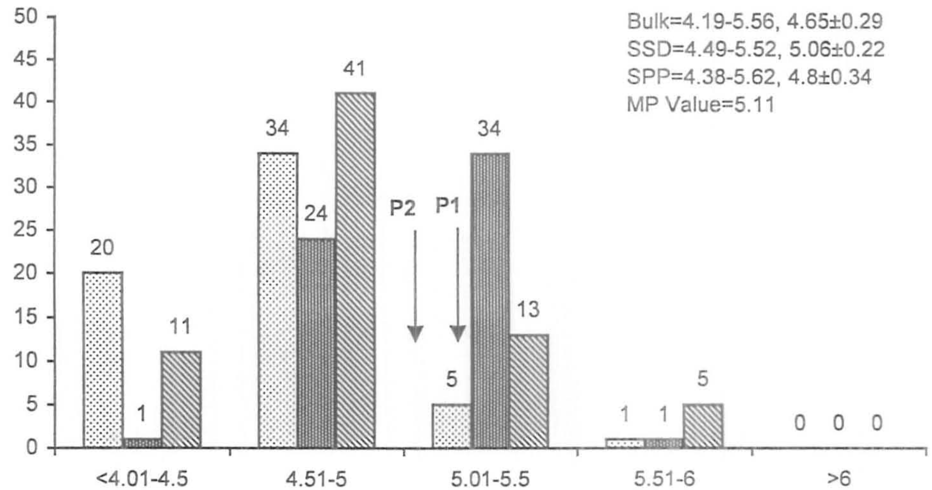


Fig. 4.1.61b. Comparison of three breeding methods for 100 seed weight plant^{-1} in 9020/Mash 3 of blackgram at NARC

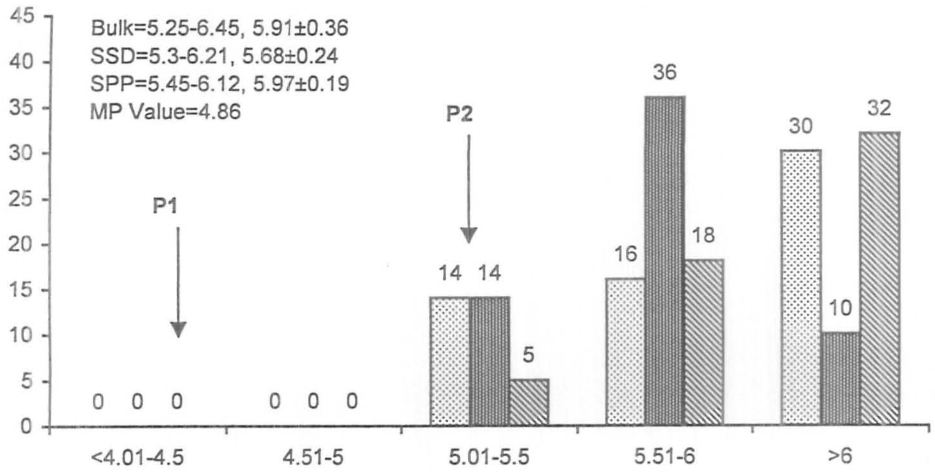


Fig. 4.1.62a. Comparison of three breeding methods for 100 seed weight plant^{-1} in 9020/Mash 1 of blackgram at FJ

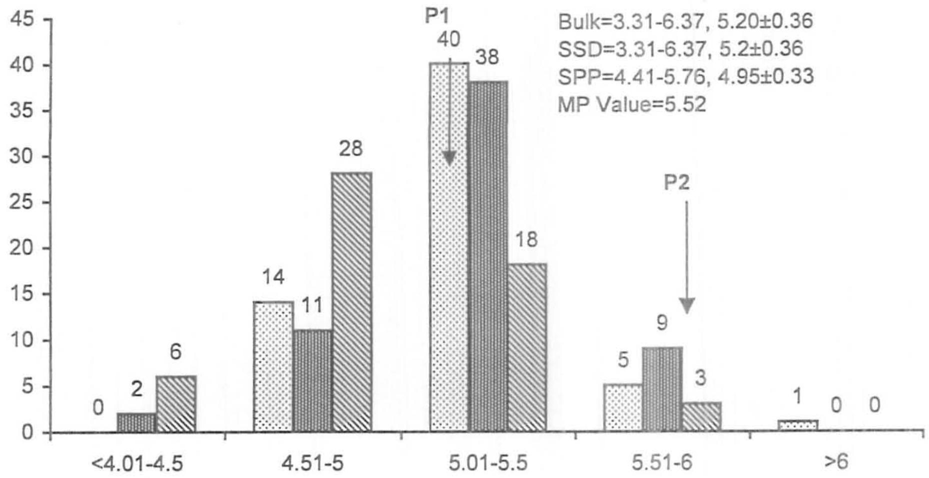


Fig. 4.1.62b. Comparison of three breeding methods for 100 seed weight plant^{-1} in 9020/Mash 1 of blackgram at NARC

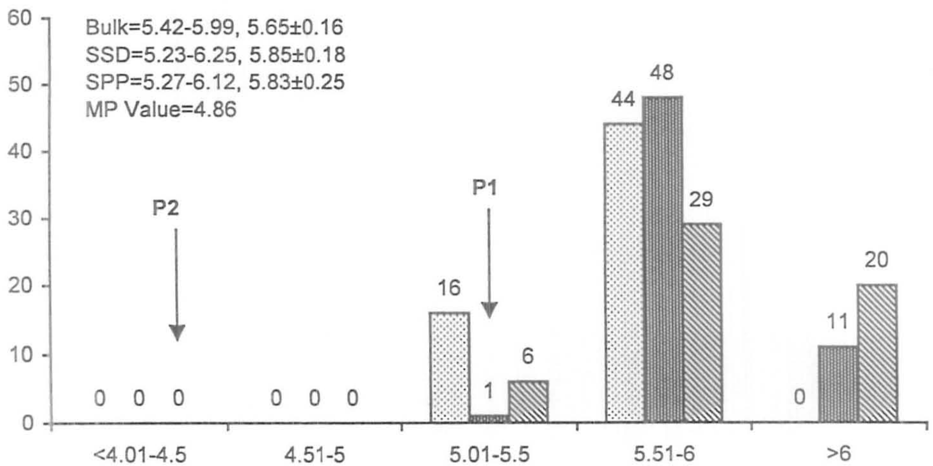


Fig. 4.1.63a. Comparison of three breeding methods for 100 seed weight plant^{-1} in Mash 1/9020 of blackgram at FJ

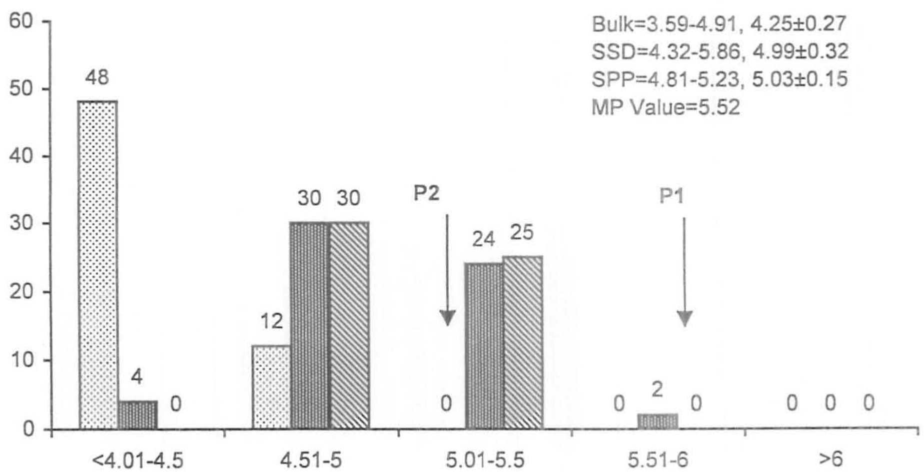


Fig. 4.1.63b. Comparison of three breeding methods for 100 seed weight plant^{-1} in Mash 1/9020 of blackgram at NARC

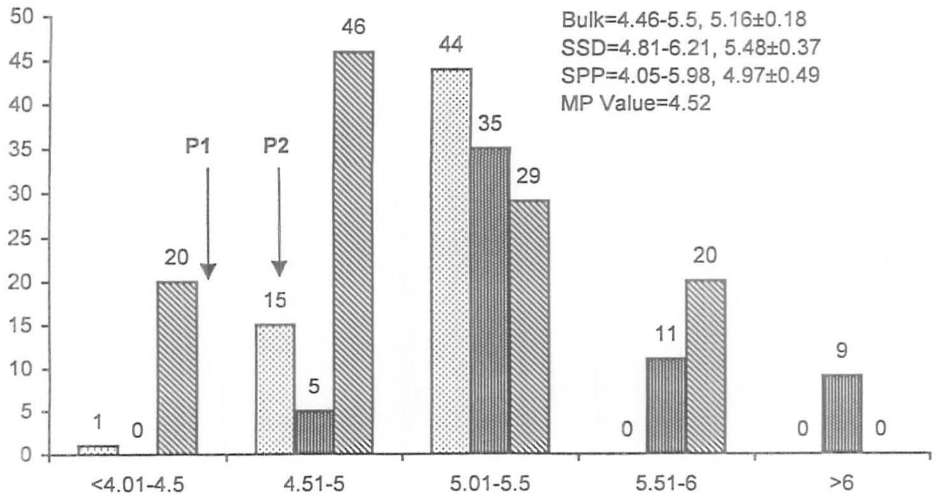


Fig. 4.1.64a. Comparison of three breeding methods for 100 seed weight plant^{-1} in 9020/9012 of blackgram at FJ

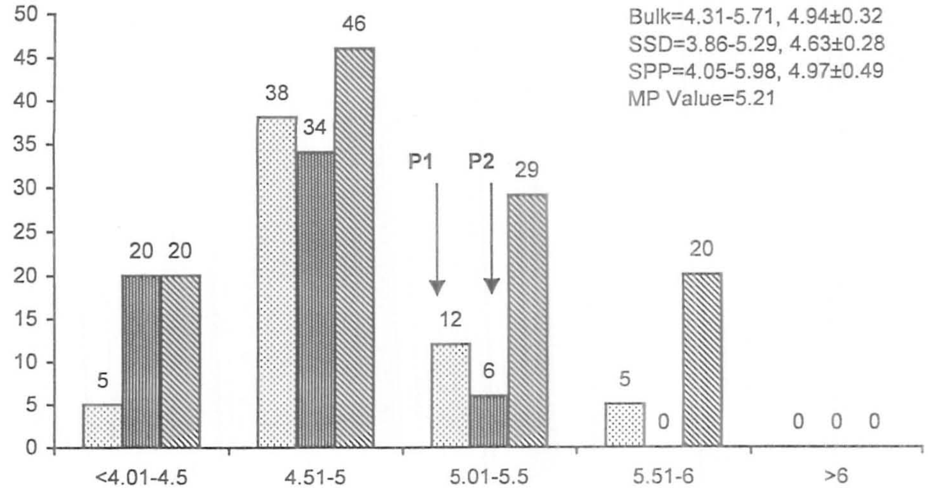


Fig. 4.1.64b. Comparison of three breeding methods for 100 seed weight plant^{-1} in 9020/9012 of blackgram at NARC

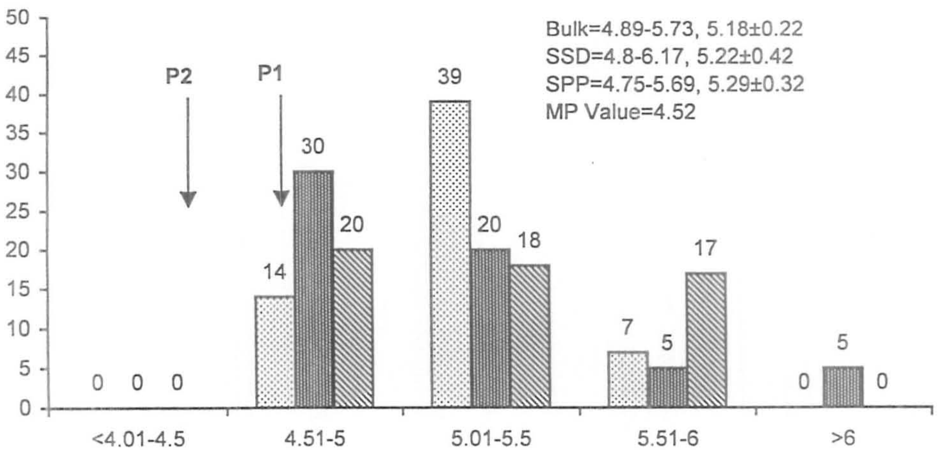


Fig. 4.1.65a. Comparison of three breeding methods for 100 seed weight plant^{-1} in 9012/9020 of blackgram at FJ

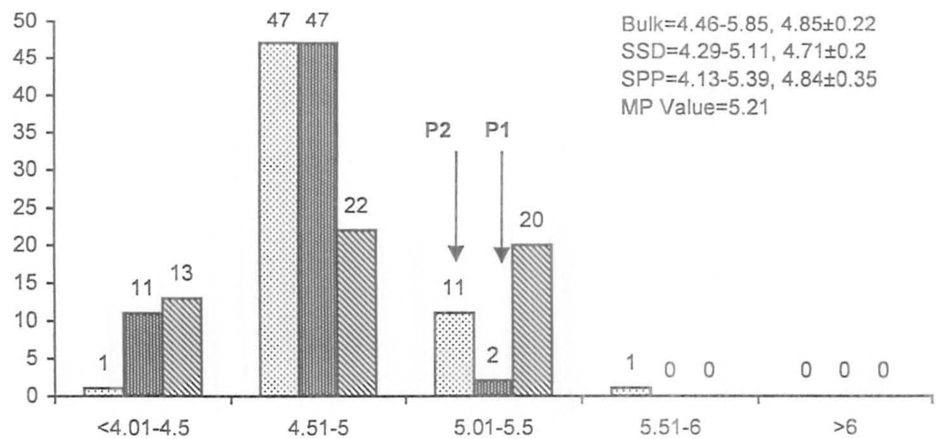


Fig. 4.1.65b. Comparison of three breeding methods for 100 seed weight plant^{-1} in 9012/9020 of blackgram at NARC

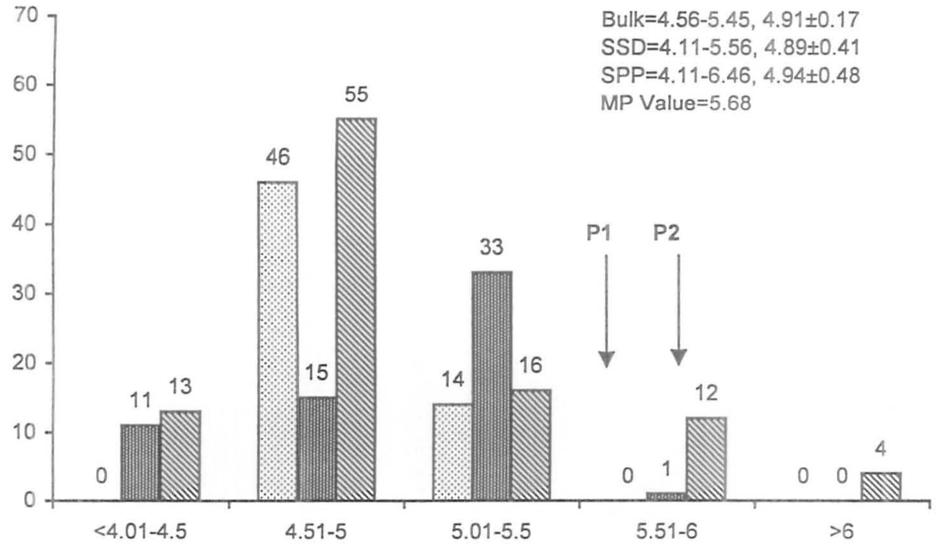


Fig. 4.1.66a. Comparison of three breeding methods for 100 seed weight plant^{-1} in 9025/9026 of blackgram at FJ

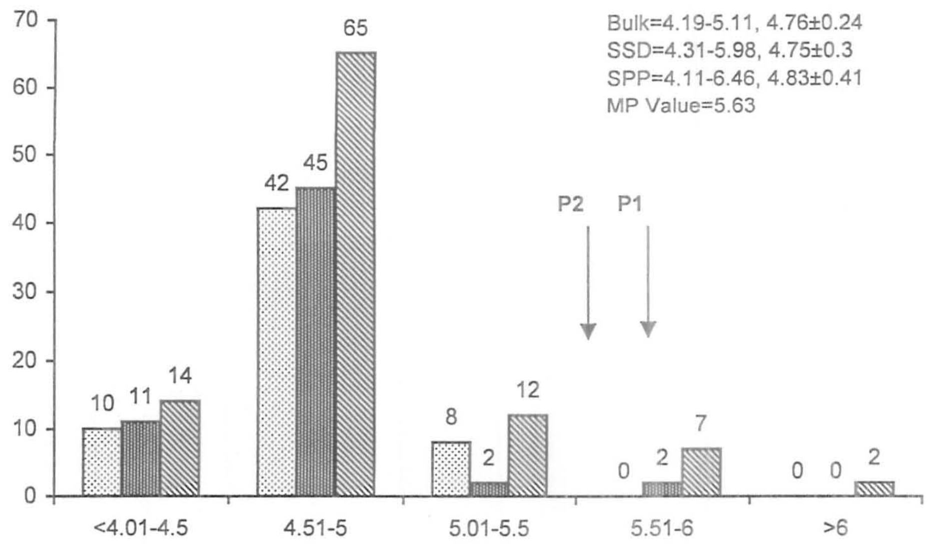


Fig. 4.1.66b. Comparison of three breeding methods for 100 seed weight plant^{-1} in 9025/9026 of blackgram at NARC

Table 4.1.8: Number of plants and their percentage over mid parents value in 100 seed weight plant^{-1} in 11 crosses at two locations.

Gen.	Location	Br. M.	M P Value	No. of sample collected	No. of plants over MP	%age over MP	M P Value	No. of sample collected	No. of plants over MP	%age over MP	M P Value	No. of sample collected	No. of plants over MP	%age over MP
			9025/Mash 1				Mash 3/Mash 1				Mash 3/9026			
F_2	NARC	SPP	4.47	30	27	90.00	4.54	30	18	60.00	4.28	30	18	60.00
F_3	NARC	SPP	4.80	50	1	2.00	4.56	50	1	2.00	4.89	50	1	2.00
F_4	NARC	SPP	5.73	145	0	0.00	5.44	160	0	0.00	5.29	120	0	0.00
F_4	FJ	SPP	5.43	145	35	24.14	5.00	160	114	71.25	5.26	120	64	53.33
F_4	FJ	BM	5.43	60	0	0.00	5.00	60	23	38.33	5.26	60	0	0.00
F_4	NARC	BM	5.73	60	1	1.67	5.44	60	0	0.00	5.29	60	0	0.00
F_4	FJ	SSD	5.43	60	1	1.67	5.00	60	45	75.00	5.26	60	0	0.00
F_4	NARC	SSD	5.73	60	0	0.00	5.44	60	0	0.00	5.29	60	0	0.00
			Mash 1/9026				9012/9025				9020/Mash 3			
F_2	NARC	SPP	4.54	30	27	90.00	4.40	30	15	50.00	4.66	30	9	30.00
F_3	NARC	SPP	5.07	50	18	36.00	4.95	50	4	8.00	4.22	50	6	12.00
F_4	NARC	SPP	5.70	105	5	4.76	5.45	100	2	2.00	5.11	70	11	15.71
F_4	FJ	SPP	5.53	105	84	80.00	5.09	100	28	28.00	4.59	70	70	100.0
F_4	FJ	BM	5.53	60	20	33.33	5.09	60	40	66.67	4.59	60	60	100.0
F_4	NARC	BM	5.70	60	0	0.00	5.45	60	2	3.33	5.11	60	4	6.67
F_4	FJ	SSD	5.53	60	20	33.33	5.09	60	12	20.00	4.59	60	60	100.0
F_4	NARC	SSD	5.70	60	0	0.00	5.45	60	1	1.67	5.11	60	23	38.33
			9020/Mash 1				Mash 1/9020				9020/9012			
F_2	NARC	SPP	4.92	30	27	90.00	4.92	30	18	60.00	4.85	30	21	70.00
F_3	NARC	SPP	4.40	50	40	80.00	4.40	50	47	94.00	4.55	50	8	16.00
F_4	NARC	SPP	5.52	55	33	60.00	5.52	55	0	0.00	5.21	115	33	28.70
F_4	FJ	SPP	4.86	55	55	100.0	4.86	55	55	100.0	4.52	115	94	81.74
F_4	FJ	BM	4.86	60	60	100.0	4.86	60	60	100.0	4.52	60	59	98.33
F_4	NARC	BM	5.52	60	4	6.67	5.52	60	0	0.00	5.21	60	9	15.00
F_4	FJ	SSD	4.86	60	60	100.0	4.86	60	60	100.0	4.52	60	60	100.0
F_4	NARC	SSD	5.52	60	5	8.33	5.52	60	2	3.33	5.21	60	1	1.67
			9012/9020				9025/9026							
F_2	NARC	SPP	4.85	30	6	20.00	4.21	30	18	60.00				
F_3	NARC	SPP	4.55	50	1	2.00	5.12	50	1	2.00				
F_4	NARC	SPP	5.21	55	7	12.73	5.63	100	5	5.00				
F_4	FJ	SPP	4.52	55	55	100.0	5.68	100	11	11.00				
F_4	FJ	BM	4.52	60	60	100.0	5.68	60	0	0.00				
F_4	NARC	BM	5.21	60	1	1.67	5.63	60	0	0.00				
F_4	FJ	SSD	4.52	60	60	100.0	5.68	60	0	0.00				
F_4	NARC	SSD	5.21	60	0	0.00	5.63	60	2	3.33				

could not prove its worth for SSD rather SPP was slightly better method at NARC (Fig. 4.1.64b).

The hybrid 9025/9026 revealed high range in SPP at both the locations but low frequency and highest frequency was observed in the range 4.5g in both the cases (Fig. 4.1.66a and b). Bulk Method and SSD were unable to produced any plant with >6g 100 seed weight at both the locations. Sixty percent plant progenies produced higher seed weight than MP in F_2 at NARC (Table 4.1.8).

4.7 Biological Yield

Biological yield is one of the most important indicators to improve grain yield; it was also obvious that larger the sample size, greater will be the chance of better selection to improve the required trait. The hybrid, 9025/Mash 1 tested at FJ revealed high level of genetic variance for biological yield as compared to NARC, Islamabad. Transgressive segregation was observed in all the three selection schemes at FJ, although in Bulk Method (BM) and Single Seed Descent (SSD) breeding methods it was low (Fig. 4.1.67a). High variances coupled with transgressive segregation were observed in Single Plant Progenies (SPP). Biological yield can be increased by selecting superior progenies in F_4 or in later generations. Similar results were observed while comparing all the three breeding methods at NARC in this cross (Fig. 4.1.67b). However, low transgressive segregation was achieved at this location especially in BM and SSD. In all the three methods at both locations transgressive segregation was observed with low biomass. It is suggested to select high yielding single plant in this cross through BM and SSD, while superior plant progenies from SPP in F_4 from this cross to increase yield potential could also be selected. On the basis of evaluation for biological yield, it was observed that SPP was the best to improve this trait both at FJ and NARC location.

As in SPP the data were recorded in all the generations, therefore, by comparing segregation over the generations, it was observed that maximum mean biological yield was recorded in F_2 where 9 plants out of 30 (30%) were better than mid parent. Biological yield was reduced in F_3 but number of superior plant over mid parent was increased that increased the scope of selection in later generations (Table 4.1.9). All the three methods compared in F_4 revealed that SPP out yielded superior segregations. Out of

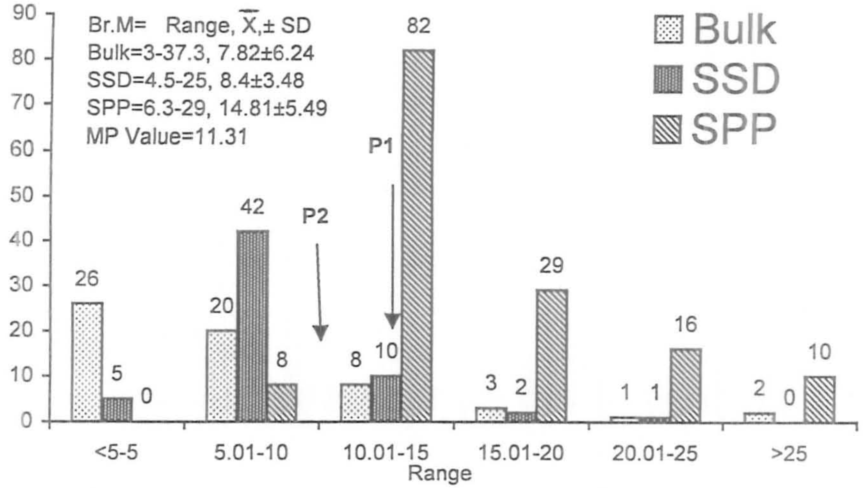


Fig. 4.1.67a. Comparison of three breeding methods for biological yield plant^{-1}in 9025/Mash 1 of blackgram at FJ

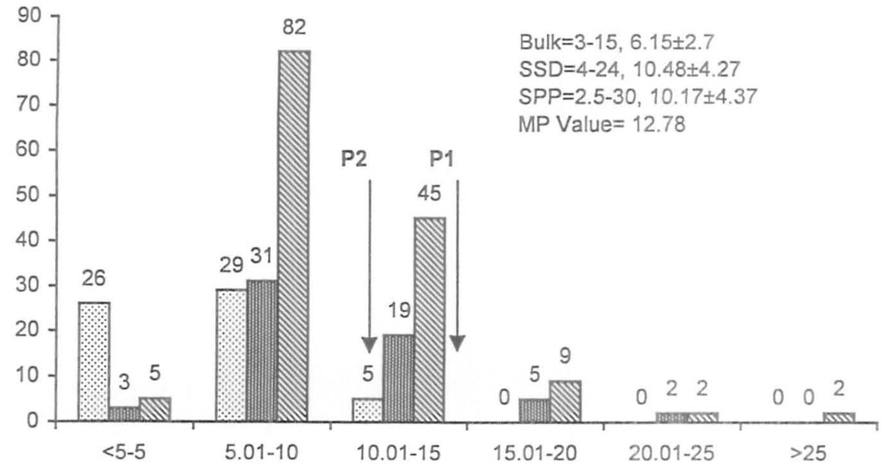


Fig. 4.1.67b. Comparison of three breeding methods for biological yield plant^{-1} in 9025/Mash 1 of blackgram at NARC

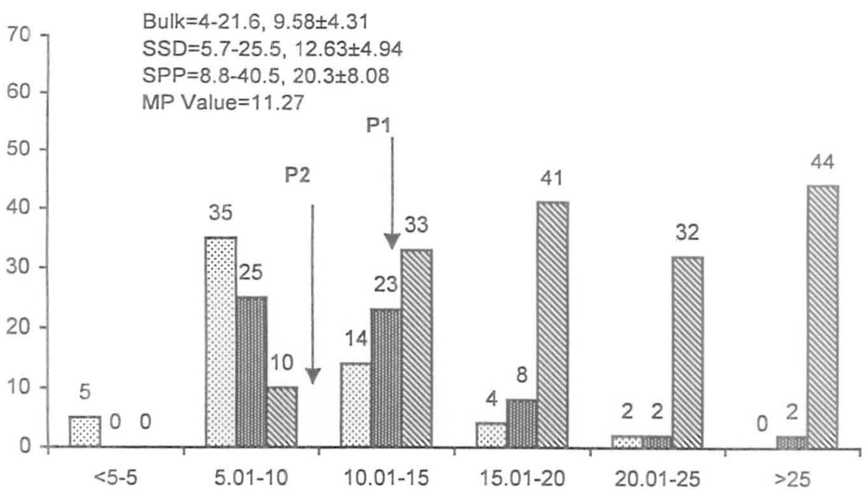


Fig. 4.1.68a. Comparison of three breeding methods for biological yield plant^{-1} in Mash 3/Mash 1 of blackgram at FJ

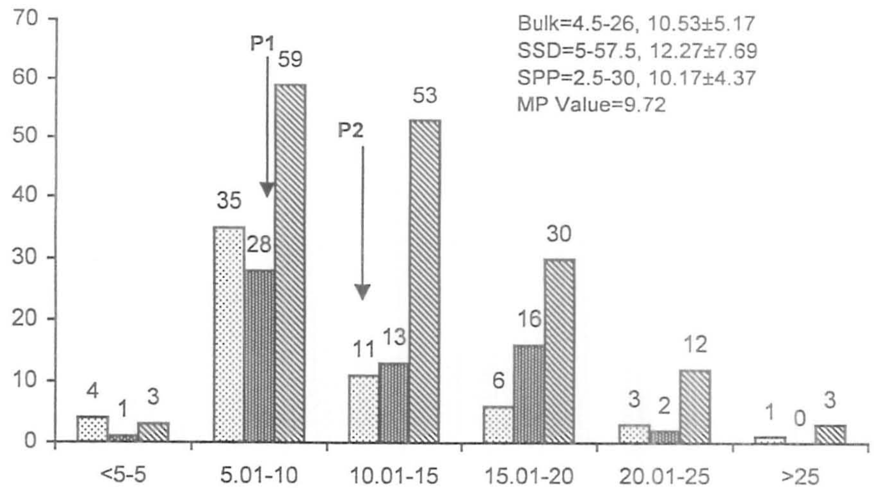


Fig. 4.1.68b. Comparison of three breeding methods for biological yield plant^{-1} in Mash 3/Mash 1 of blackgram at NARC

145 progenies 97 (66.9%) were superior to mid parent. For improving biological yield the hybrid 9025/Mash 1 revealed SPP as a suitable breeding method.

Both the parents used in the hybrid Mash 3/Mash 1are approved varieties. Mash 3 is of a short duration, whereas Mash 1 is high yielding and bold seeded. Fig. 4.1.68a indicates that high frequency of transgressive segregation was observed in case of SPP in this cross, while low positive transgressive segregation was achieved in BM and SSD breeding methods. The same cross produced normal distribution for biological yield at NARC (Fig. 4.1.68b), whereas at FJ the distribution is not normal at proposed class interval.

While comparing both the locations for three breeding methods for this cross, it is clear that at FJ, SPP gave better chance to selection for biological yield as compared to NARC where the selection intensity for biologically better genotypes were decreased. However, selection for biological yield was expected slightly more at NARC than at the FJ, especially from the range >15 g plant^{-1} biomass in all the three breeding methods.

F_2 population at NARC produced higher biological yield over mid parent, 21 plant progenies (70%) were better in biological yield at NARC (Table 4.1.9), whereas, in F_3 generation 28% plant progenies were superior over mid parent in SPP. However, maximum percentage was recorded in F_4 generation in SPP at FJ, where 138 (86.25%) plant progenies were better in biological yield over mid parent, whereas at NARC 104 plant progenies (65 %) were better over mid parent in this cross (Table 4.1.9).

The hybrid Mash 3/9026 exhibited similar results at both the locations in BM and SSD, whereas in SPP, high range for biological yield was observed at FJ (Fig. 4.1.69a and b). High mean values of biological yield at FJ indicated that more positive transgressive segregation in SPP was obtained as compared to NARC. Twenty eight plants in SPP were observed with high biological yield, i. e., > 25g plant^{-1} that could be due to one of the parent (Mash 3) being an approved variety for rainfed areas. A continuous decrease of desirable transgressive segregants in this cross at NARC in all the three breeding method was indicating limited scope for improving biological yield in this cross, in areas with better moisture regime as at NARC. Maximum percentage (65%) over mid parent was observed in SSD at NARC where 39 plant progenies were better than mid parent in F_4 (Table 4.1.9). It was followed by SPP breeding method, where 70 plant progenies (58.3%) were better in biological yield over their mid parent at FJ.

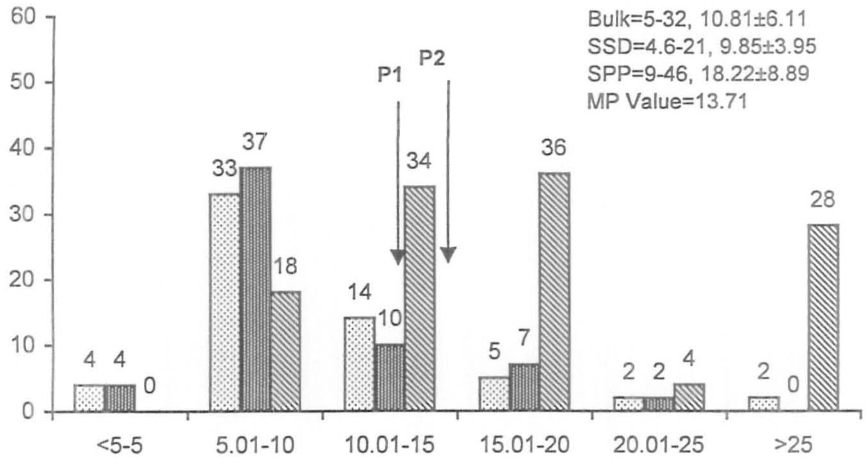


Fig. 4.1.69a Comparison of three breeding methods for biological yield plant^{-1} in Mash 3/9026 of blackgram at FJ

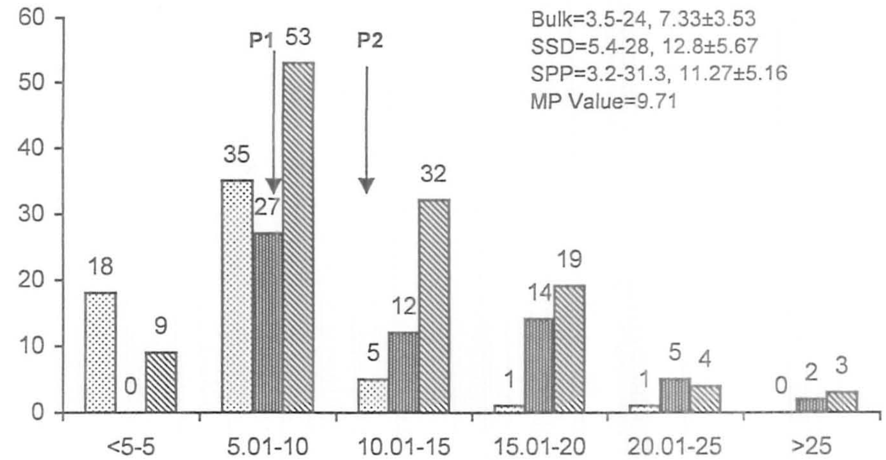


Fig. 4.1.69b. Comparison of three breeding methods for biological yield plant^{-1} in Mash 3/9026 of blackgram at NARC

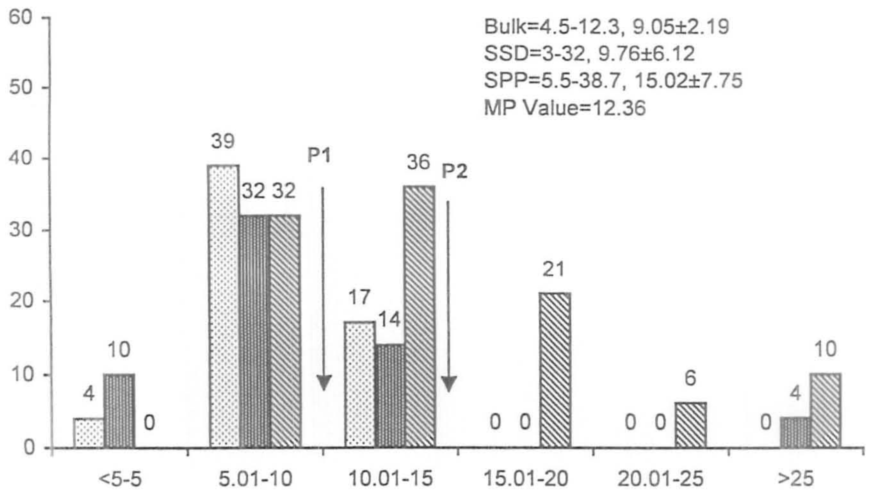


Fig. 4.1.70a. Comparison of three breeding methods for biological yield plant^{-1} in Mash 1/9026 of blackgram at FJ

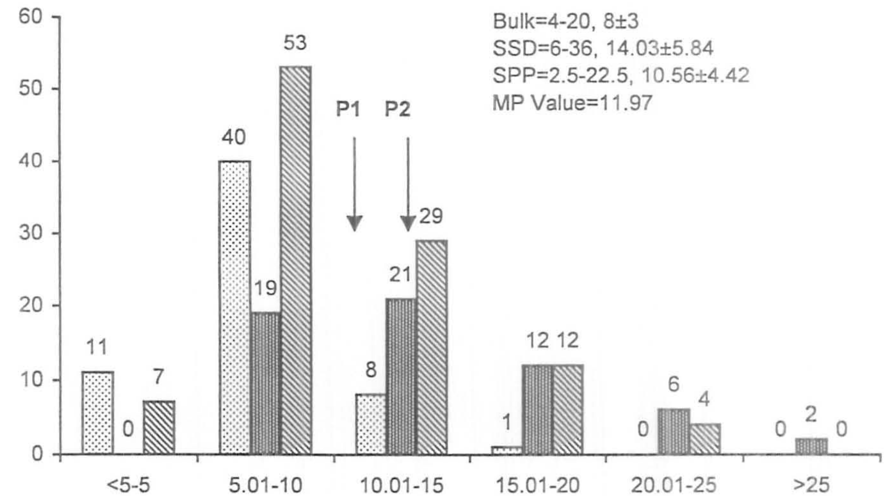


Fig. 4.1.70b. Comparison of three breeding methods for biological yield plant^{-1} in Mash 1/9026 of blackgram at NARC

In the cross Mash 1/9026 continuous variation was observed at both the location (Fig. 4.1.70a and b), but more desirable results were in SPP breeding method for biological yield. However, limited positive transgressive segregation was also achieved in SSD at NARC. Bulk and SSD breeding methods produced least positive transgressive segregation at FJ and less or no desirable plant in BM at NARC. Whereas, continuous variation was recorded, indicating additive nature of gene action at NARC. While comparing segregation over the generation, it was observed that maximum plants (38) which were 63.3% in SSD at NARC, superior to mid parent. In SPP breeding method at FJ, 56.2% plant progenies were superior in biological yield over mid parent.

Bulk and SSD breeding methods revealed similar performance at both the locations in cross 9012/9025 (Fig. 4.1.71a and b). In SPP method this cross observed higher segregation at FJ as compared to NARC. Bulk Method revealed very low range at NARC, whereas, it was high at FJ. At FJ this hybrid did not exhibit any plant for biomass <10g plant^{-1} in SPP that revealed limitation for selection of low biological yield at this location. Ninety one plant progenies were superior over their mid parent in F_4 in SPP breeding method at FJ location, and this was followed by the same method in F_3 and F_4 at NARC. The results of F_2 to F_4 generations indicated that percentage gain in biological yield from lower generation to higher generation was increasing, revealing additive type of gene action. It may be suggested that for this trait selection from F_4 and later generations, could yield promising material.

The results obtained in 9020/Mash 3 cross at FJ indicated that there were transgressive segregation for biological yield in SSD and SPP breeding procedures but its frequency was relatively low (Fig. 4.1.72a). In this cross Bulk breeding method failed to enhance biological yield in later generations at both the locations. At NARC, almost similar results were obtained with a little difference that SSD had slightly higher frequency for its transgressive segregates (Fig. 4.1.72b). On the average this hybrid was not likely to enhance biological yield in blackgram. As already stated that Mash 3 is a variety suitable for rainfed areas, therefore, at FJ this cross exhibited better performance for SPP as compared to NARC where water availability is higher than FJ due to higher precipitation.

Fifty three plant progenies (75.71%) proved superior in biological yield over mid parent in SPP in F_4 at FJ. However, maximum percentage over mid parents was observed

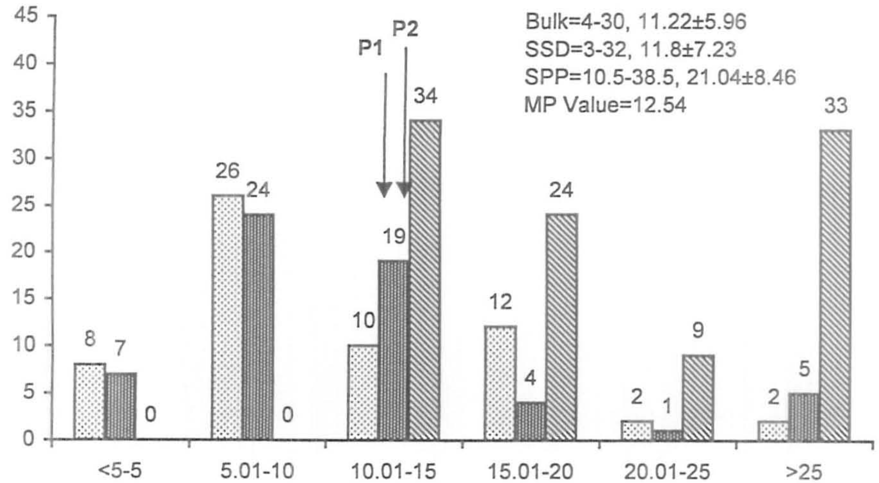


Fig. 4.1.71a. Comparison of three breeding methods for biological yield plant^{-1} in 9012/9025 of blackgram at FJ

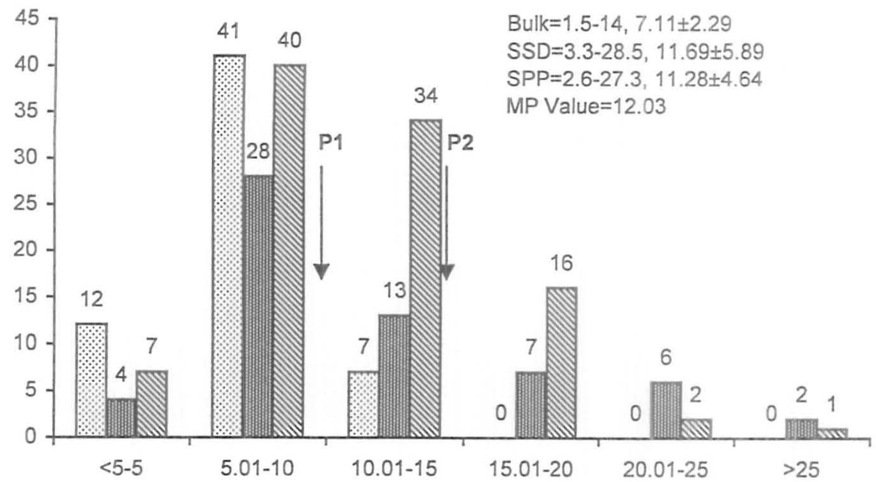


Fig. 4.1.71b. Comparison of three breeding methods for biological yield plant^{-1} in 9012/9025 of blackgram at NARC

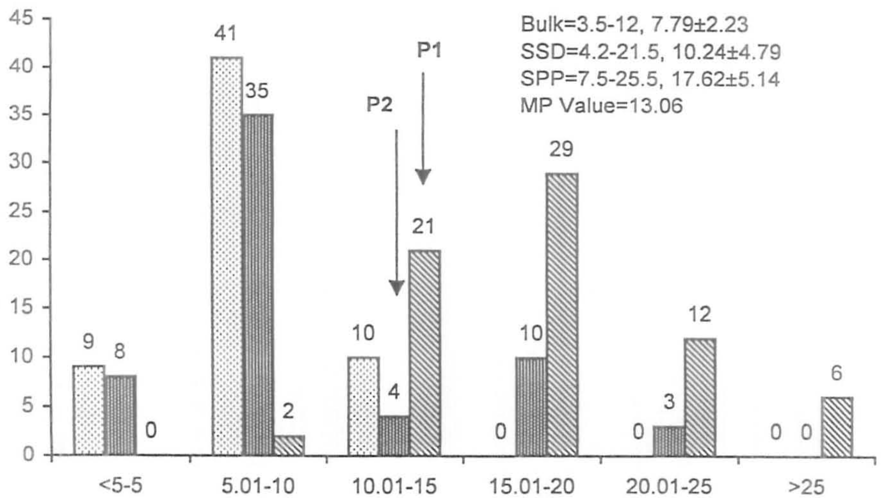


Fig. 4.1.72a. Comparison of three breeding methods for biological yield plant^{-1} in 9020/Mash 3 of blackgram at FJ

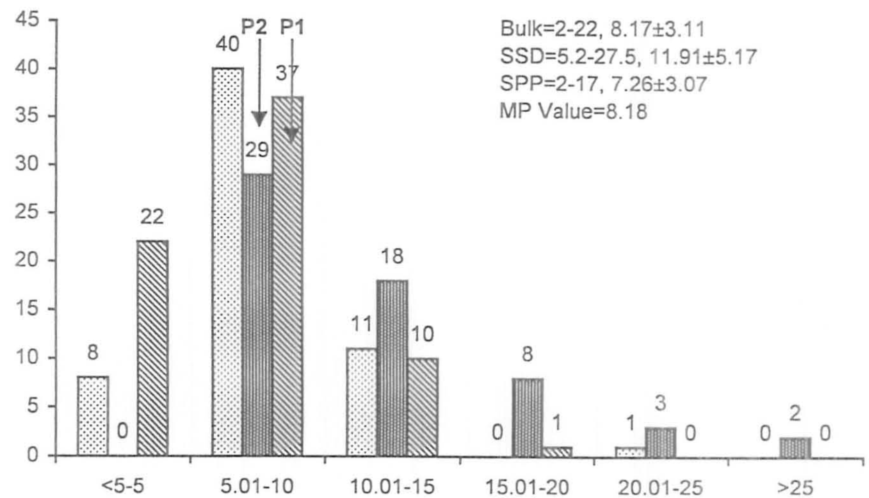


Fig. 4.1.72b. Comparison of three breeding methods for biological yield plant^{-1} in 9020/Mash 3 of blackgram at NARC

in SSD at NARC, where percentage over mid parent was 76.67% for this trait in this cross. Bulk Method ranks third where 30 plant progenies (50%) were observed superior over mid parent in F_4 at NARC (Table 4.1.9).

In cross, 9020/Mash 1 positive transgressive pattern at FJ location (Fig. 4.1.73a) was observed. However, it was relatively higher in SPP and SSD breeding methods at both the location. The frequency for biomass ranging from 15 to 20 g was high in BM at NARC (Fig. 4.1.73b) as compared to FJ. The pattern of additive gene action indicated scope of selection for biological yield at both the location in all the three breeding procedures. Due to presence of high amount of transgressive segregation, this hybrid needs to be evaluated carefully during next generations. This hybrid could be potential for selecting high yielding blackgram cultivars because Mash 1 is high yielding and 9020 is an erect type with long pods.

The desirable plants from this cross are expected from F_4 at both the location. The selected plants are suggested to evaluate under a wide range of environments. Out of these two parents 9020 is an erect, bold seeded and medium yielding cultivar, whereas Mash 1 is semi erect, bold seeded, tall and high in yield. Maximum number of plant progenies (46 plants out of 55) were superior over mid parent in SPP at FJ for biological yield, whereas, 66.67% plants proved better in yield over mid parent in BM at NARC, this was followed by SSD where 65% plant population was better to mid parent at NARC (Table 4.1.9). In this cross it was revealed that maximum gain in biological yield was achieved in F_4 as compared to early generations indicating high magnitude of additive gene effect. So selection can be effective in F_4 or in later generations to select biologically superior plants.

The reciprocal hybrid (Mash 1/9020) of these parents gave a changed pattern at both the locations (Fig 4.1.74), especially for SPP at NARC. No plant with very low biological yield was observed at FJ, although at NARC low frequency was observed in BM and SSD. In SPP high frequency was recorded in the range closer to parents at both the location.

High amount of transgressive segregation was observed in all the breeding methods at FJ, in cross Mash 1/9020 whereas, SPP failed to produce high biological yield at NARC (Fig. 4.1.74a and b). This hybrid indicated the reciprocal effects, even in early generations hence it was retained for further study. Forty three plant progenies (78.18%)

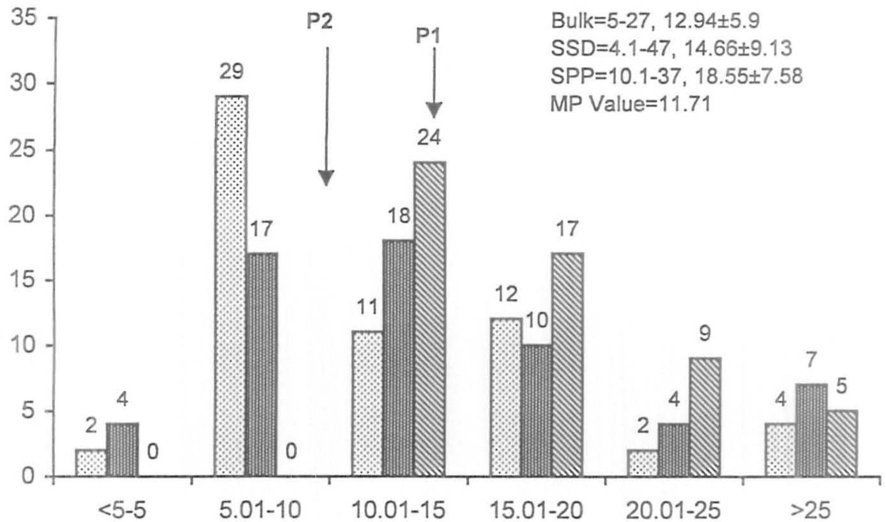


Fig. 4.1.73a. Comparison of three breeding methods for biological yield plant^{-1} in 9020/Mash 1 of blackgram at FJ

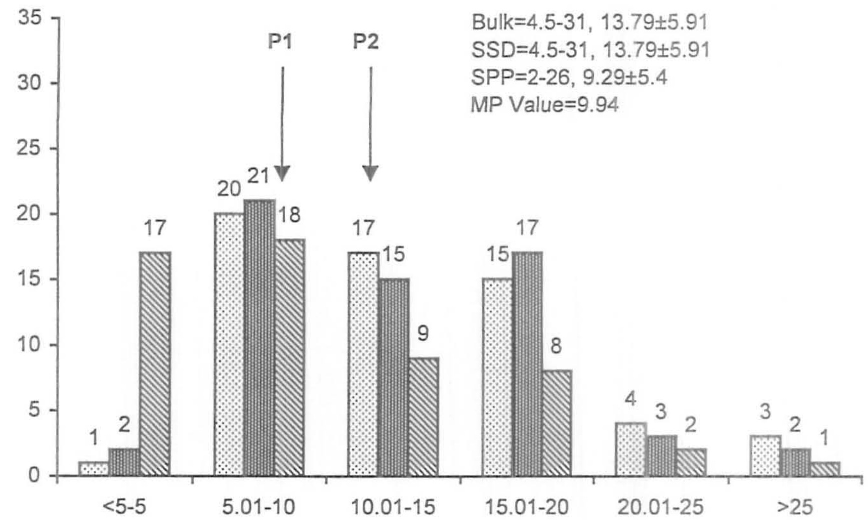


Fig. 4.1.73b. Comparison of three breeding methods for biological yield plant^{-1} in 9020/Mash 1 of blackgram at NARC

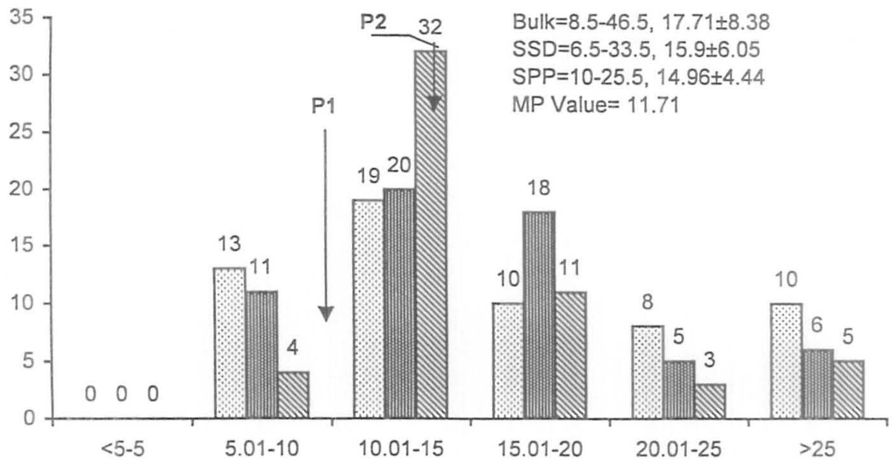


Fig. 4.1.74a. Comparison of three breeding methods for biological yield plant^{-1} in Mash 1/9020 of blackgram at FJ

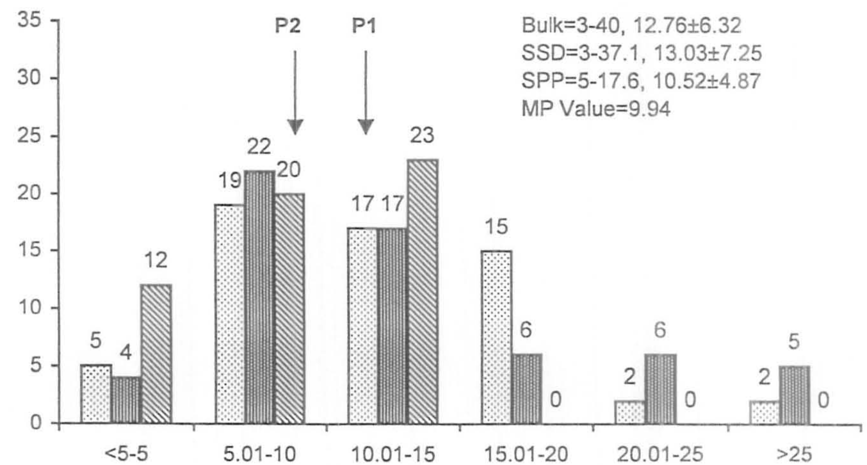


Fig. 4.1.74b. Comparison of three breeding methods for biological yield plant^{-1} in Mash 1/9020 of blackgram at NARC

were superior over mid parent value in SPP in this cross at FJ in F_4 (Table 4.1.9). While 71.67% plant population (43 plants) were superior in biological yield than mid parent in bulk breeding method at FJ in F_4 generation. Forty two plant progenies were better yielder over mid parent in SSD at FJ. Over all results indicated that selection for biological yield was effective in F_4 with special attention to BM and SSD at NARC.

The cross 9020/9012 comprised of an erect (9020) and semi erect (9012) parents. The effect of male parent that was low in biological yield expressed even in F_4 (Fig. 4.1.75a). More than 90% plant progenies were lower than MP for biological yield at both locations. All the three breeding methods gave low amount of positive transgressive segregation at both the locations in this hybrid including reciprocal cross. The reciprocal hybrid (9012/9020) was slightly better especially at FJ (Fig 4.1.76a). As for biological yield is concerned this cross could not prove its worth for improving this trait either under better moisture regime or rainfed conditions.

Thirty nine (65%) and 38 (63.3) plant progenies were observed superior to mid parent in cross 9020/9012 in SSD and in BM in F_4 at NARC and FJ, respectively (Table 4.1.9). However, Bulk Method at FJ produced 35 plant progenies (58.35%) which were superior over mid parent in this cross. Twenty nine plant progenies were better than mid parent in F_3. Generation mean of this reciprocal cross revealed that 36 plant progenies (65.45%) were observed better over mid parent in F_4 in SPP breeding method at FJ. However, SSD ranked second where 30 plant progenies with 50% plant population were better yielder over their mid parent in F_4 generation at NARC. Almost similar results were obtained in bulk method at FJ and in SPP at NARC in this cross. On the whole, these two crosses did not exhibit better performance at NARC, whereas SPP was better in reciprocal cross at FJ and small amount of superior progenies are expected.

The hybrid 9025/9026 evaluated at both the location revealed similar results, although it performed better for BM at FJ. Low frequency was recorded for biological yield with >15g at both the locations (Fig. 4.1.77a and b). Thirty four plant progenies (68%) were better over mid parent in F_3 in SPP breeding method, 60% in F_2, nineteen plant progenies were better in F_4 in SSD at FJ (Table 4.1.9).

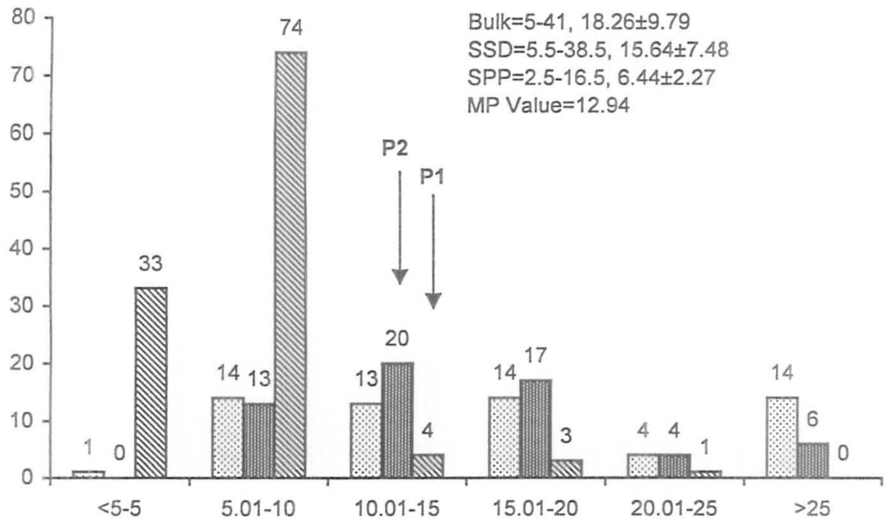


Fig. 4.1.75a. Comparison of three breeding methods for biological yield plant^{-1} in 9020/9012 of blackgram at FJ

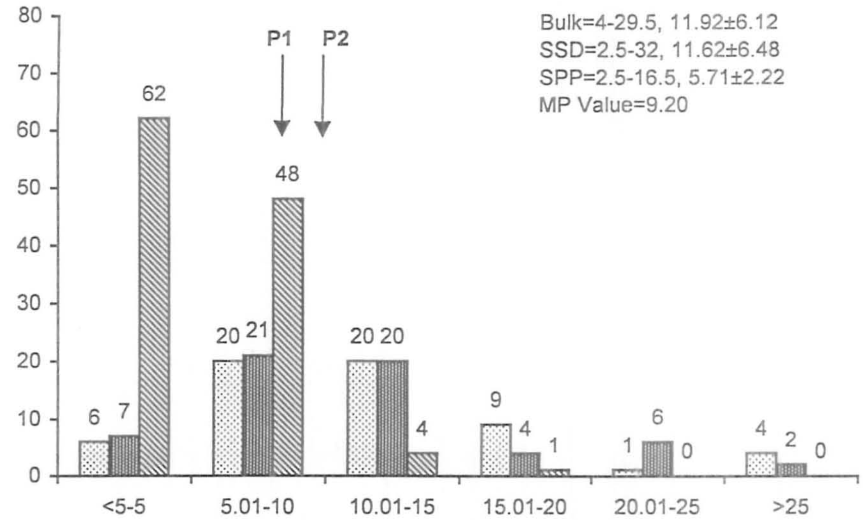


Fig. 4.1.75b. Comparison of three breeding methods for biological yield plant^{-1} in 9020/9012 of blackgram at NARC

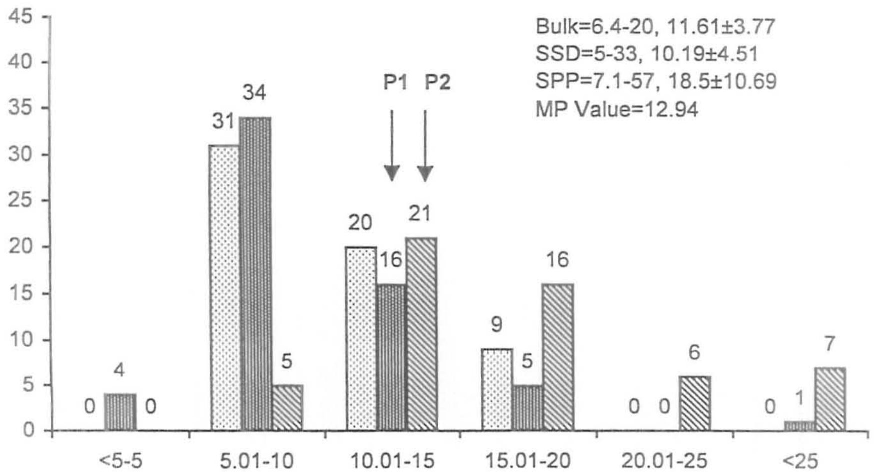


Fig. 4.1.76a. Comparison of three breeding methods for biological yield plant^{-1} in 9012/9020 of blackgram at FJ

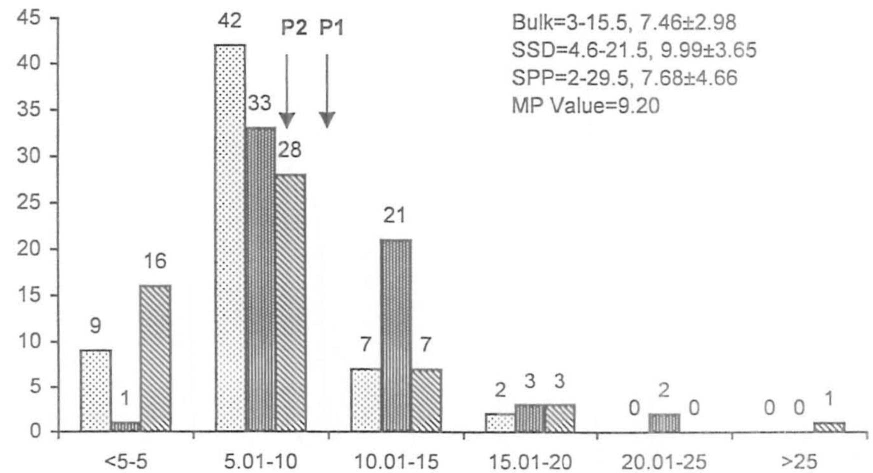


Fig. 4.1.76b. Comparison of three breeding methods for biological yield plant^{-1} in 9012/9020 of blackgram at NARC

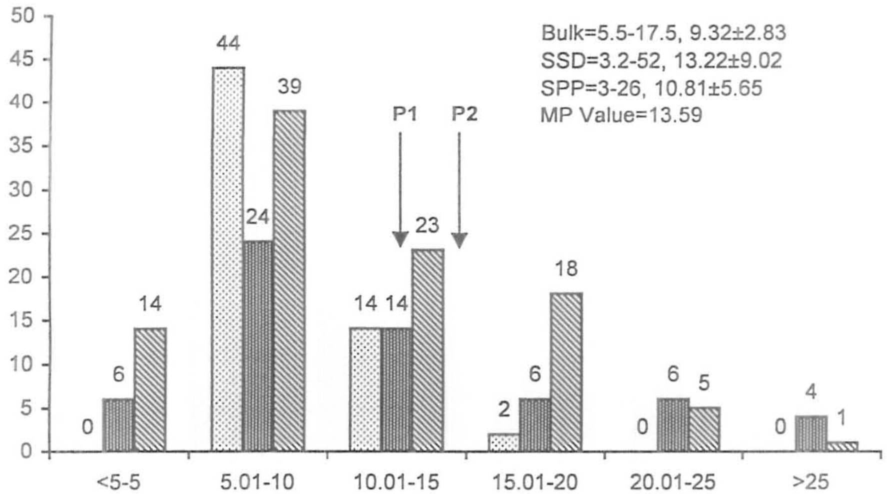


Fig. 4.1.77a. Comparison of three breeding methods for biological yield plant^{-1} in 9025/9026 of blackgram at FJ

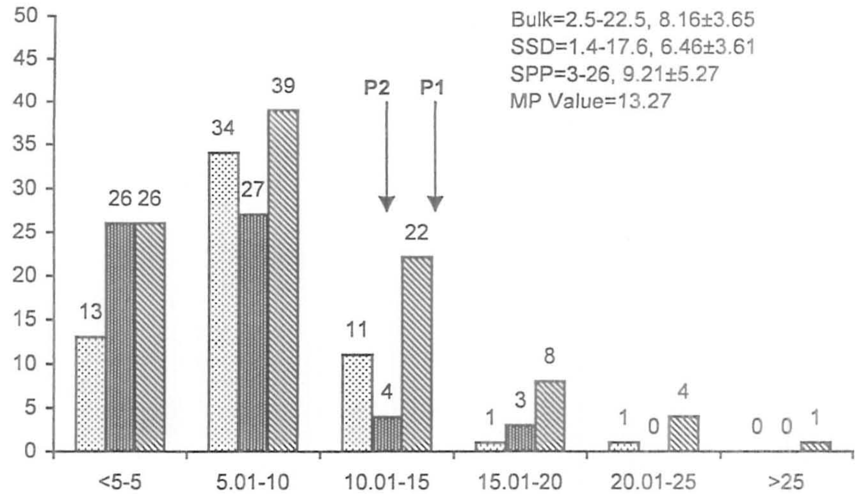


Fig. 4.1.77b. Comparison of three breeding methods for biological yield plant^{-1} in 9025/9026 of blackgram at NARC

Table 4.1.9: Number of plants and their percentage over mid parents value in biological yield plant^{-1} in 11 crosses at two locations.

Gen.	Location	Br. M.	M P Value	No. of sample collected	No. of plants over MP	%age over MP	M P Value	No. of sample collected	No. of plants over MP	%age over MP	M P Value	No. of sample collected	No. of plants over MP	%age over MP
			9025/Mash 1				**Mash 3/Mash 1**				**Mash 3/9026**			
F_2	NARC	SPP	28.15	30	9	30.00	28.53	30	21	70.00	21.3	30	15	50.00
F_3	NARC	SPP	14.90	50	13	26.00	17.36	50	14	28.00	11.06	50	28	56.00
F_4	NARC	SPP	11.31	145	34	23.45	9.72	160	104	65.00	9.71	120	62	51.67
F_4	FJ	SPP	12.78	145	97	66.90	11.27	160	138	86.25	13.71	120	70	58.33
F_4	FJ	BM	11.31	60	10	16.67	11.27	60	17	28.33	13.71	60	15	25.00
F_4	NARC	BM	12.78	60	3	5.00	9.72	60	25	41.67	9.71	60	11	18.33
F_4	FJ	SSD	11.31	60	9	15.00	11.27	60	33	55.00	13.71	60	9	15.00
F_4	NARC	SSD	12.78	60	14	23.33	9.72	60	33	55.00	9.71	60	39	65.00
			Mash 1/9026				**9012/9025**				**9020/Mash 3**			
F_2	NARC	SPP	27.33	30	15	50.00	26.20	30	9	30.00	35.19	30	12	40.00
F_3	NARC	SPP	13.97	50	15	30.00	10.58	50	31	62.00	11.64	50	19	38.00
F_4	NARC	SPP	11.97	105	36	34.29	12.03	100	39	39.00	8.18	70	19	27.14
F_4	FJ	SPP	12.36	105	59	56.19	12.54	100	91	91.00	13.06	70	53	75.71
F_4	FJ	BM	12.36	60	0	0.00	12.54	60	20	33.33	13.06	60	0	0.00
F_4	NARC	BM	11.97	60	5	8.33	12.03	60	1	1.67	8.18	60	30	50.00
F_4	FJ	SSD	12.36	60	10	16.67	12.54	60	17	28.33	13.06	60	14	23.33
F_4	NARC	SSD	11.97	60	38	63.33	12.03	60	22	36.67	8.18	60	46	76.67
			9020/Mash 1				**Mash 1/9020**				**9020/9012**			
F_2	NARC	SPP	41.21	30	15	50.00	41.21	30	18	60.00	39.26	30	9	30.00
F_3	NARC	SPP	14.55	50	16	32.00	14.55	50	16	32.00	10.15	50	29	58.00
F_4	NARC	SPP	9.94	55	23	41.82	9.94	55	29	52.73	9.2	115	6	5.22
F_4	FJ	SPP	11.71	55	46	83.64	11.71	55	43	78.18	12.94	115	2	1.74
F_4	FJ	BM	11.71	60	29	48.33	11.71	60	43	71.67	12.94	60	35	58.33
F_4	NARC	BM	9.94	60	40	66.67	9.94	60	37	61.67	9.20	60	38	63.33
F_4	FJ	SSD	11.71	60	33	55.00	11.71	60	42	70.00	12.94	60	39	65.00
F_4	NARC	SSD	9.94	60	39	65.00	9.94	60	37	61.67	9.2	60	34	56.67
			9012/9020				**9025/9026**							
F_2	NARC	SPP	39.26	30	6	20.00	20.91	30	18	60.00				
F_3	NARC	SPP	10.15	50	5	10.00	8.69	50	34	68.00				
F_4	NARC	SPP	90.20	55	15	27.27	13.27	100	17	17.00				
F_4	FJ	SPP	12.94	55	36	65.45	13.59	100	28	28.00				
F_4	FJ	BM	12.94	60	17	28.33	13.59	60	8	13.33				
F_4	NARC	BM	9.20	60	13	21.67	13.27	60	5	8.33				
F_4	FJ	SSD	12.94	60	14	23.33	13.59	60	19	31.67				
F_4	NARC	SSD	9.20	60	30	50.00	13.27	60	6	10.00				

4.1.8 Grain Yield

Grain yield is the most important trait in any legume crop. To improve grain yield combination of desired traits, hybridization is undertaken among genotypes superior in various traits followed by appropriate selection procedure. The hybrid 9025/Mash 1, tested for grain yield at both the locations to compare three breeding methods, revealed high frequency coupled with high range in SPP at both the locations while SSD at NARC and BM at FJ also gave high range and frequency (Fig. 4.1.78a and b). Bulk Method could not produce any plant with >6g grain yield plant^{-1} at NARC while at FJ, SSD was unable to give progenies with more than 7g grain yield except one i.e., higher than 10g plant^{-1}. Thus this progeny need special attention in the next generations. Table 4.1.10 revealed that maximum 85 plants out of 145 were better in SPP for grain yield plant^{-1} in F_2 at FJ than mid parent and it was 12 better plants in F_2 at NARC.

The hybrid, Mash 3/Mash 1 produced high transgressive segregation and frequency in all the breeding methods at NARC, while at FJ only SPP gave better results with higher positive transgressive segregation (Fig. 4.1.79a and b). However, 91 progenies at FJ produced more than 7g grain yield as compared with NARC, where 33 plants were in this category for rainfed areas. This indicated that the hybrid has potential that can be exploited through SPP by selecting superior progenies in F_4 and tested in yield trials. Critical look of Fig. 4.1.79a and b revealed that other two methods were not much effective to improve grain in this cross. Both the parents are approved varieties, and Mash 3 is predominantly recommended for rainfed areas. Segregation at this stage indicated predominance of Mash 3 under rainfed conditions. Eighty percent plant progenies (128 out of 160) were observed superior in SPP to MP at FJ in F_4 and it was followed by SPP at NARC, where 108 plant progenies were better in grain yield over MP (Table 4.1.10). This strengthens our previous explanation.

The crosses Mash 3/9026 and Mash 1/9026 exhibited high frequency and higher ranges for grain yield in SPP. At both locations a similar performance was observed (Fig. 4.1.80a & b and 4.1.81a & b). Single Seed Descent also showed transgressive segregants with a high range at both the locations for this trait, but the range was narrow at FJ. Single Plant Progenies gave the highest frequency as compared to other methods in the range of >10g grain yield plant^{-1} at FJ in both the crosses. Table 4.1.10 indicated that 69 plants out of 120 in SPP at FJ were better than MP in F_4 in cross Mash 3/9026 while 55%

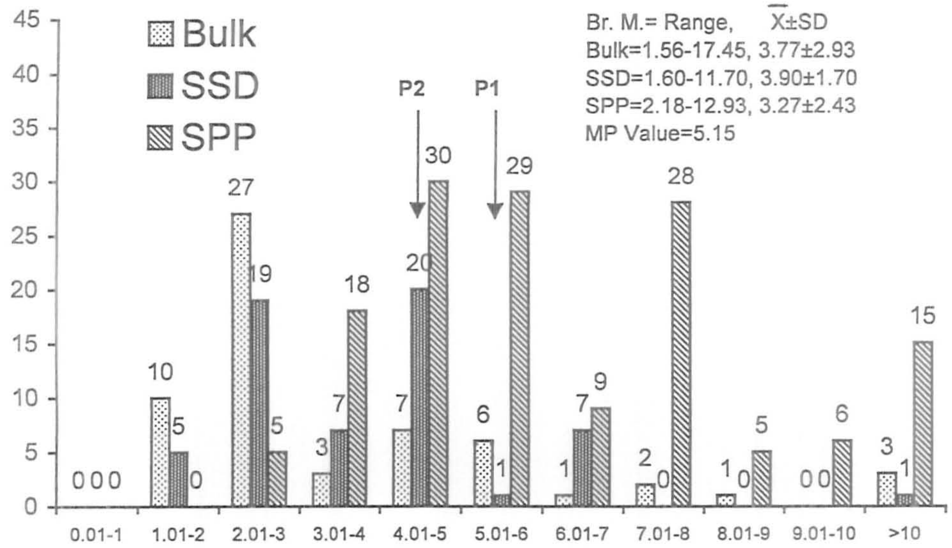


Fig. 4.1.78a. Comparison of three breeding methods for grain yield plant^{-1} in 9025/Mash 1 of blackgram at FJ

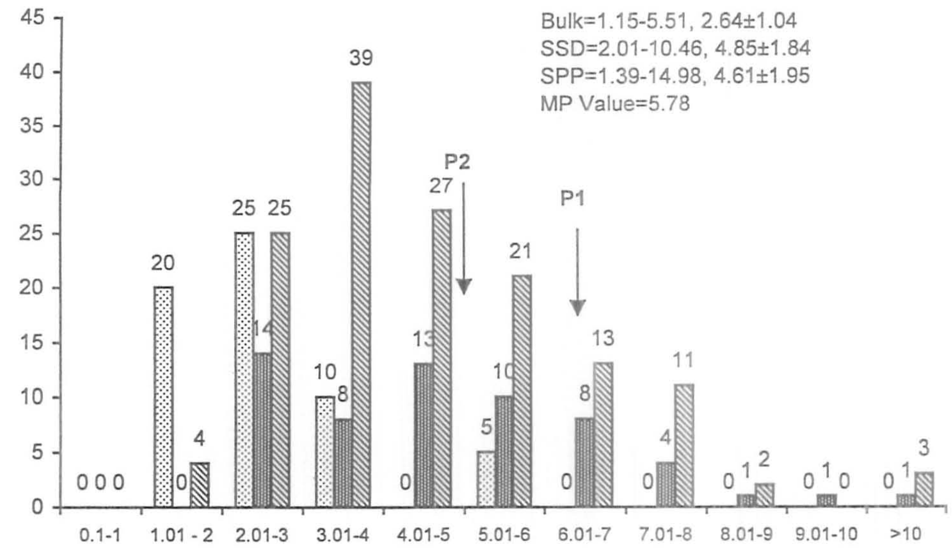


Fig. 4.1.78b. Comparison of three breeding methods for grain yield plant^{-1} in 9025/Mash 1 of blackgram at NARC

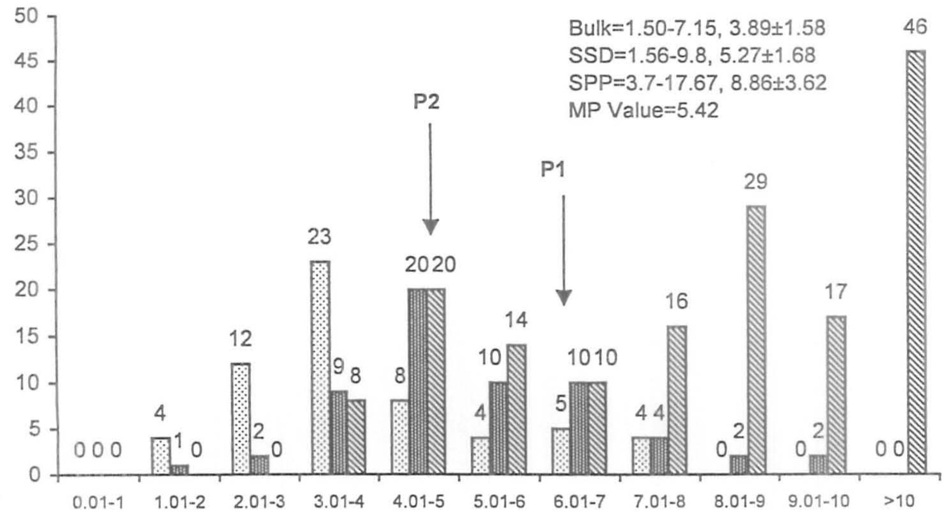


Fig. 4.1.79a. Comparison of three breeding methods for grain yield plant^{-1} in Mash 3/Mash 1 of blackgram at FJ

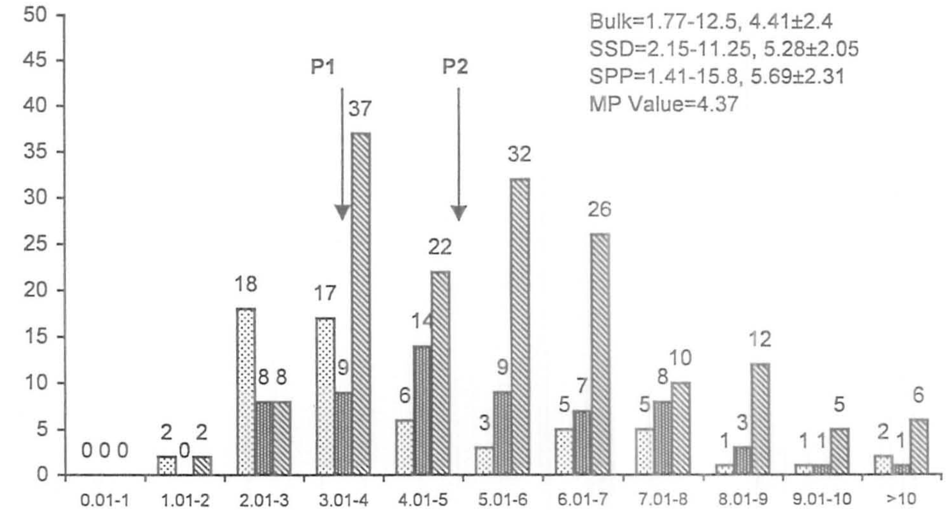


Fig. 4.1.79b. Comparison of three breeding methods for grain yield plant^{-1} in Mash 3/Mash 1 of blackgram at NARC

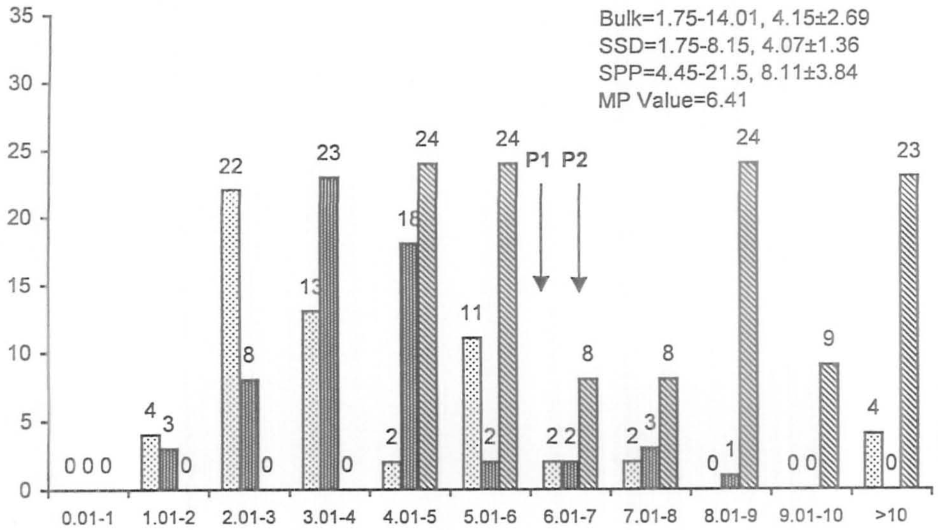


Fig. 4.1.80a. Comparison of three breeding methods for grain yield plant[-1] in Mash 3/9026 of blackgram at FJ

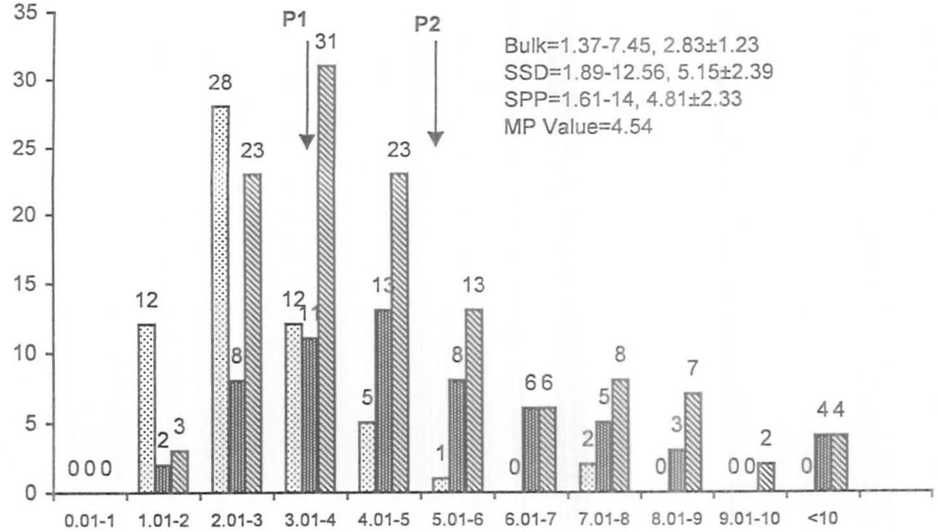


Fig. 4.1.80b. Comparison of three breeding methods for grain yield plant^{-1} in Mash 3/9026 of blackgram at NARC

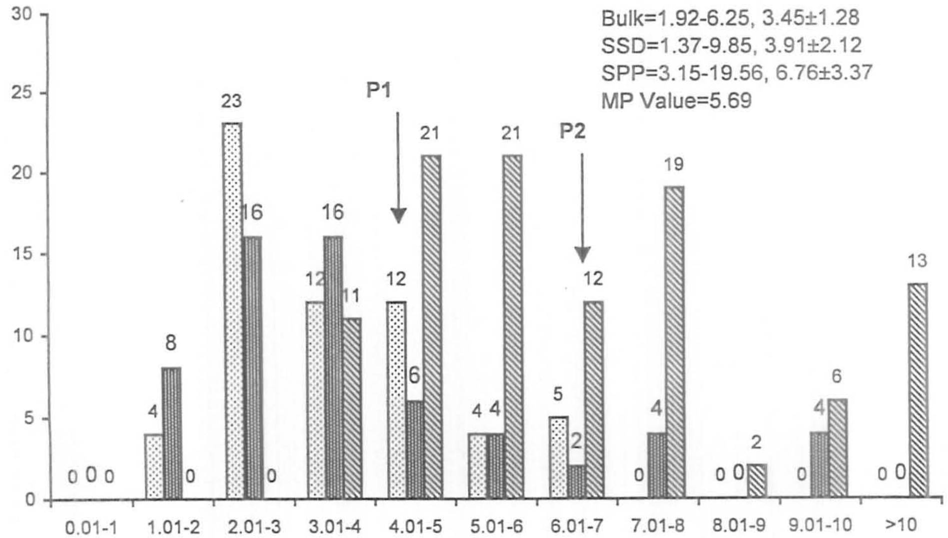


Fig. 4.1.81a. Comparison of three breeding methods for grain yield plant^{-1} in Mash 1/9026 of blackgram at FJ

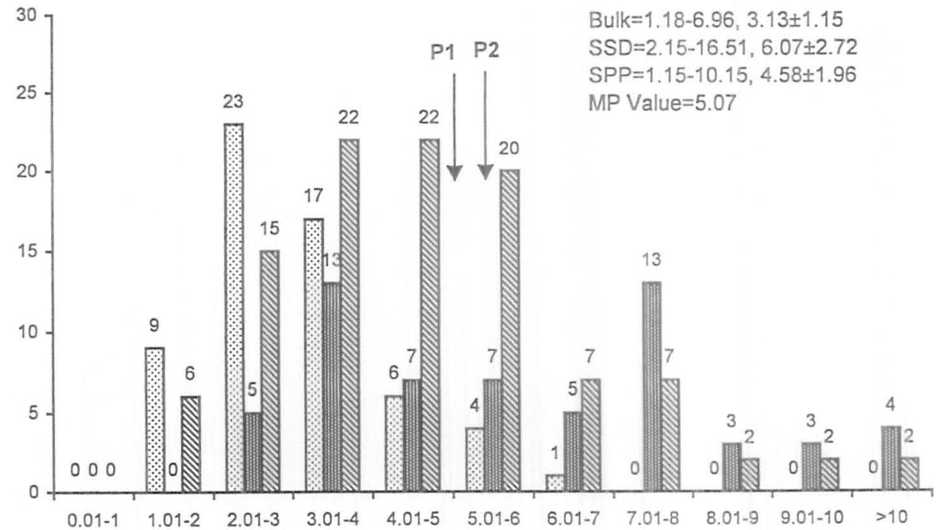


Fig. 4.1.81b. Comparison of three breeding methods for grain yield plant^{-1} in Mash 1/9026 of blackgram at NARC

plant progenies were superior in SSD at NARC in this cross. Single Plant Progenies produced 62% in F_3) and 60% in (F_2) better plant progenies at NARC.

The hybrid 9012/9025 produced high frequencies in SSD and SPP at both the location (Fig. 4.1.82a and b). Single Plant Progenies exhibited extremely high frequency for producing more than 10g grain yield at FJ, while at NARC only one progeny produced more than 10gm plant^{-1}. Bulk Method did not produce high grain yield at both the locations, hence this method did not prove its validity to improve grain yield in this cross. Maximum 91 plant progenies out of 100 were observed better in grain yield over MP in SPP at FJ and were followed by F_2 and F_3 where 50.0% plant progenies in each case were superior for this trait (Table 4.1.10). Single Seed Descent also produced 43.0% better plants in F_4 at FJ. Forty seven plant progenies gave average grain yield but more than 7g plant^{-1} at FJ, whereas four plant progenies were in this range at NARC.

The hybrid 9020/Mash 3 exhibited high frequency and wide range at FJ for grain yield plant^{-1}, while at NARC Single Seed Descent revealed high positive range and high mean value (Fig. 4.1.83a and b). Single Plant Progenies showed positive transgressive segregants at NARC for grain yield plant^{-1}. In blackgram this range of grain yield is quite appropriate for exploitation of grain yield potential, hence this hybrid is expected to produce high yielding pure lines in later generations. Table 4.1.10 shows that 75.7% (53 out of 70) plants progenies were better than MP in SPP at FJ and 71.7% were superior in SSD at NARC for grain yield plant^{-1}. Single Plant Progenies produced 30 better plant progenies at NARC in F_4.

High mean value in SPP and wide range in SSD were observed in hybrid 9020/Mash 1 at FJ, while at NARC all the breeding methods contributed towards positive transgressive segregation in this cross (Fig. 4.1.84a and b). Table 4.1.10 revealed 81.8% better plant progenies at FJ in SPP, while 44 plant progenies out of 60 were superior in BM and SSD in both the cases at NARC in F_4. In F_2, 80.0% plant progenies performed better over the MP at NARC in SPP breeding method.

The hybrid Mash 1/9020 tested at both the locations for grain yield plant^{-1} revealed high frequency coupled with high mean value in BM at both the locations (Fig. 4.1.85a and b). Single Plant Progenies did not depict plants with high grain yield at both the locations. Seventy percent plant progenies (42 out of 60) were better than MP in BM at NARC and were followed by 60.0% in F_2 and in F_4 generation at FJ and NARC,

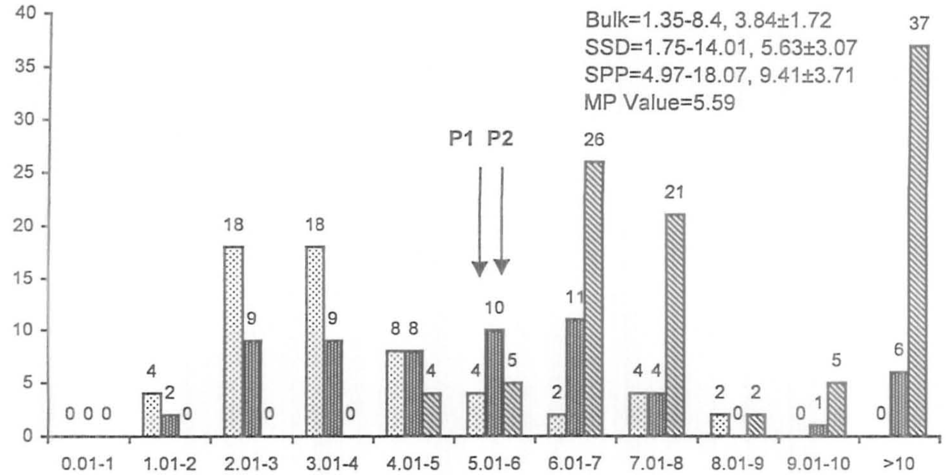


Fig. 4.1.82a. Comparison of three breeding methods for grain yield plant^{-1} in 9012/9025 of blackgram at FJ

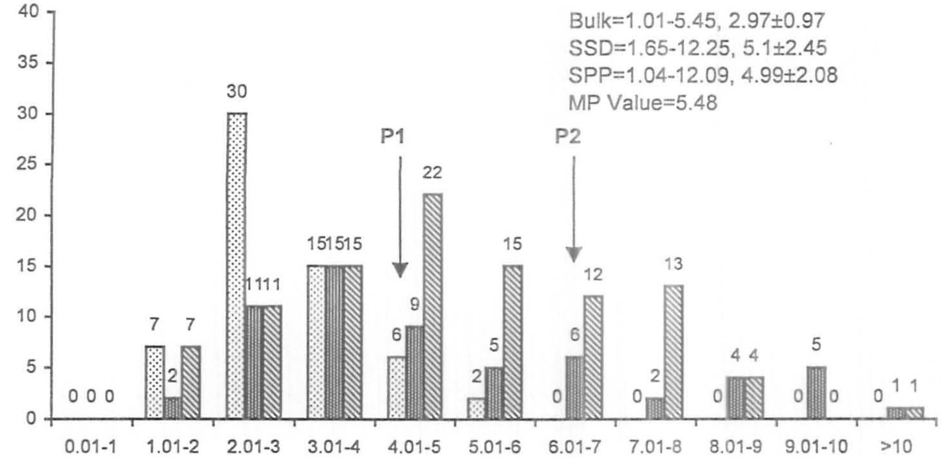


Fig. 4.1.82b. Comparison of three breeding methods for grain yield plant^{-1} in 9012/9025 of blackgram at NARC

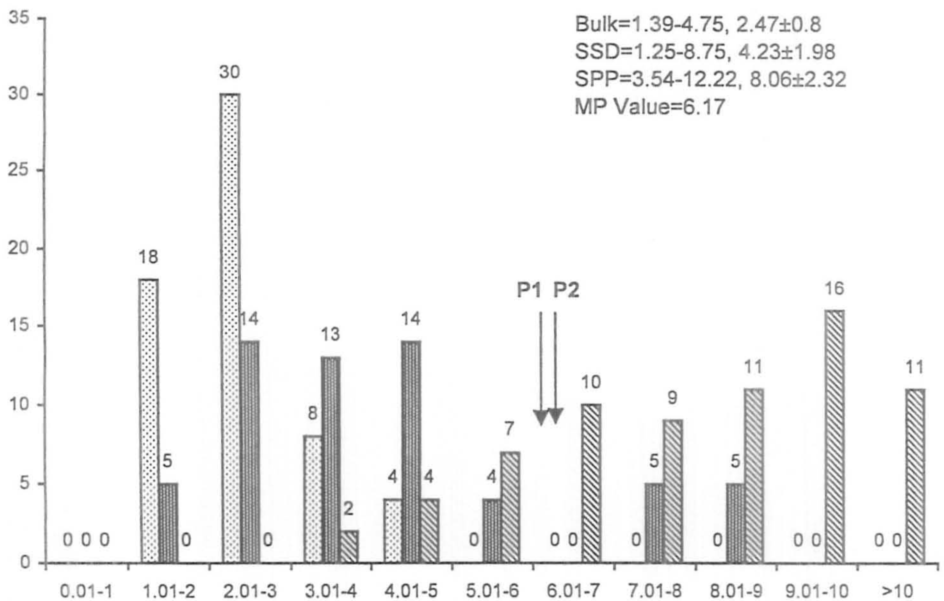


Fig. 4.1.83a. Comparison of three breeding methods for grain yield plant^{-1} in 9020/Mash 3 of blackgram at FJ

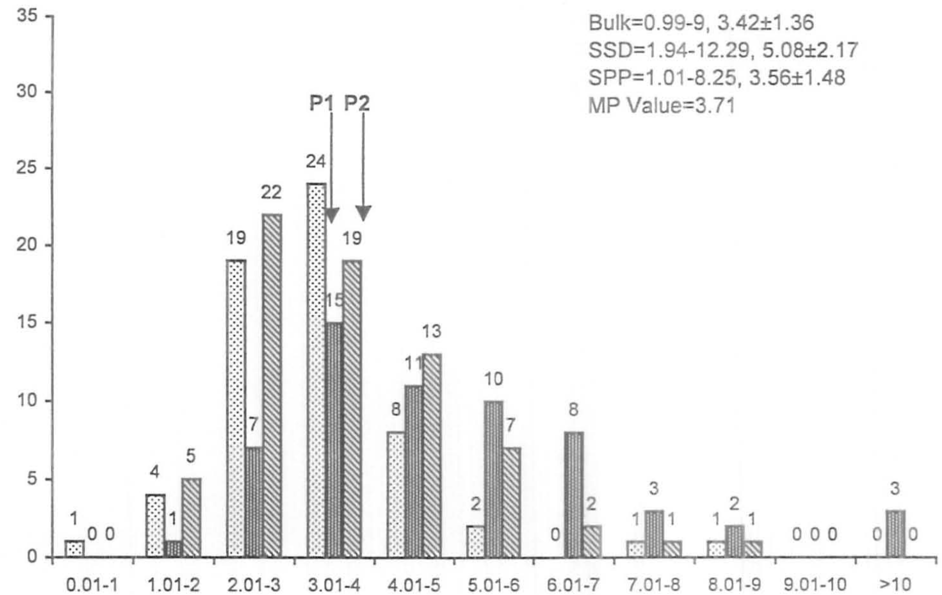


Fig. 4.1.83b. Comparison of three breeding methods for grain yield plant^{-1} in 9020/Mash 3 of blackgram at NARC

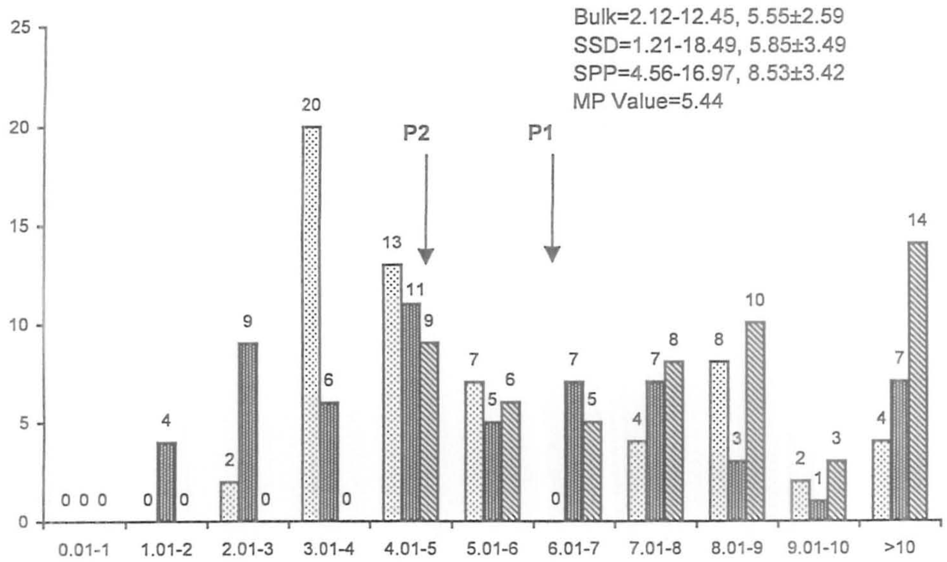


Fig. 4.1.84a. Comparison of three breeding methods for grain yield plant^{-1} in 9020/Mash 1 of blackgram at FJ

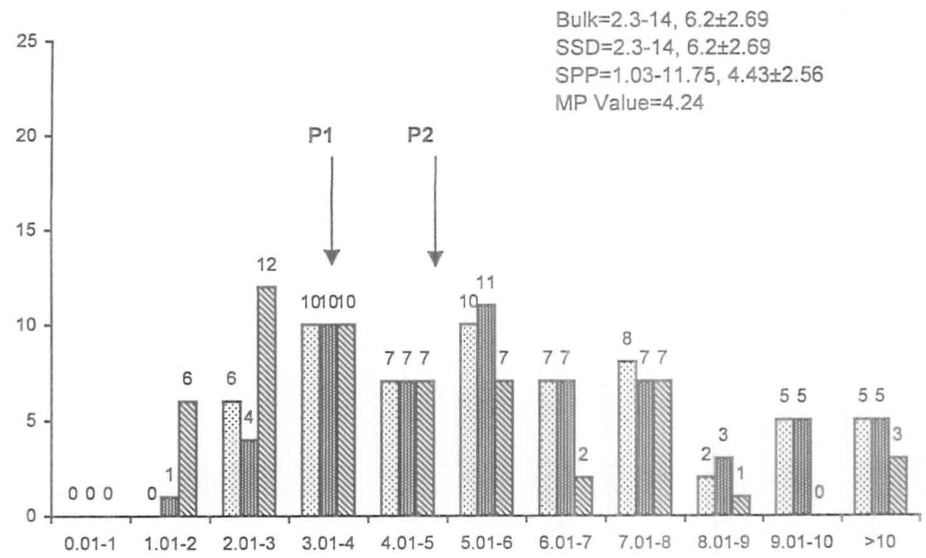


Fig. 4.1.84b. Comparison of three breeding methods for grain yield plant^{-1} in 9020/Mash 1 of blackgram at NARC

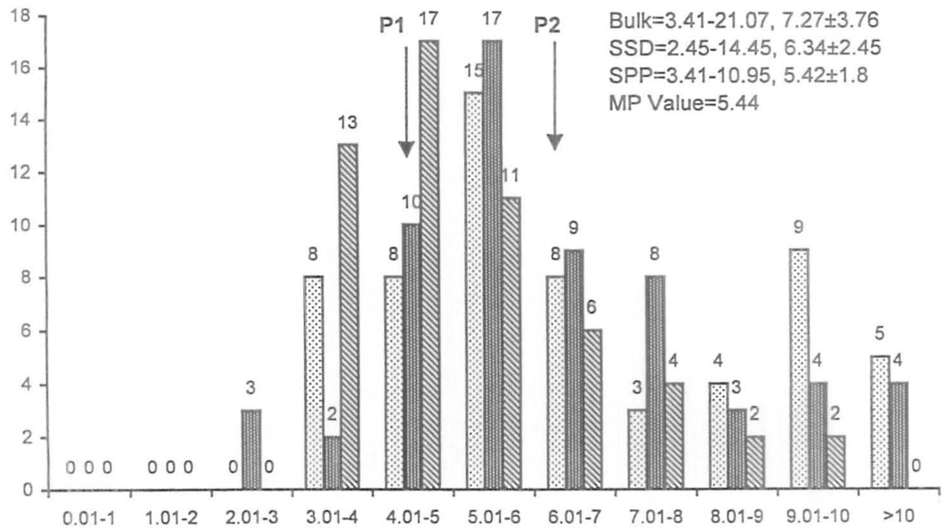


Fig. 4.1.85a. Comparison of three breeding methods for grain yield plant^{-1} in Mash 1/9020 of blackgram at FJ

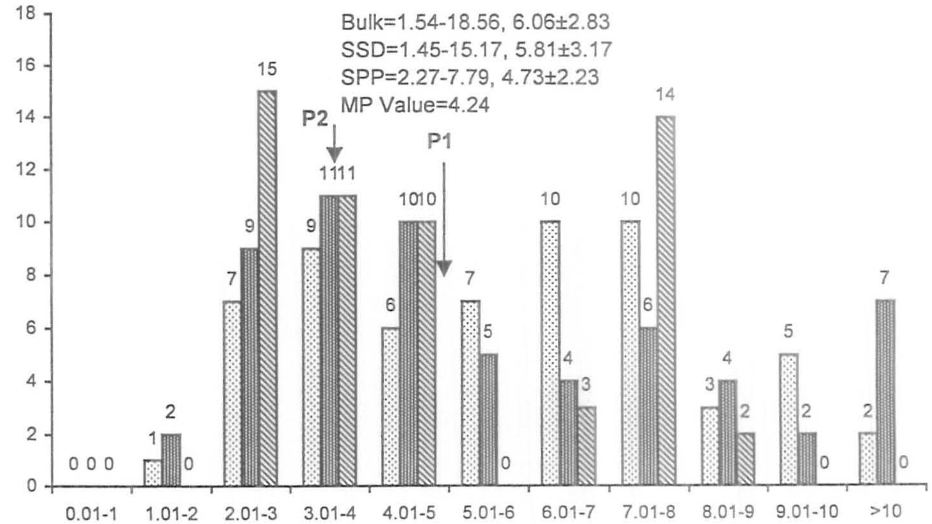


Fig. 4.1.85b. Comparison of three breeding methods for grain yield plant^{-1} in Mash 1/9020 of blackgram at NARC

respectively (Table 4.1.10). At FJ, SPP produced 21 plant progenies out of 55 which were superior to mid parent in F_4. It is interesting to note that BM proved its worth for improving grain yield at both the locations in this cross. Although different breeding methods behaves differently in their performance with parents and environmental conditions. Hence, it is very important to establish breeding methodology in relation to parentage and environmental conditions.

The hybrid 9020/9012 revealed high mean values coupled with high range in BM and it was followed by SSD at both the location for grain yield plant^{-1} (Fig. 4.1.86a and b). However, over all performance of this cross was not encouraging for improving grain yield. Reciprocal cross presented in Figure 4.1.87a and b also revealed similar results at both the locations, although SPP were slightly better at FJ. Table 4.1.10 indicated that 63.3% plant progenies were better for this trait over MP in SSD at NARC in F_4. Fifty three percent plant progenies were observed superior to MP in reciprocal cross (9012/9020) in SSD at NARC.

The hybrid 9025/9026 revealed high range with high mean values in SSD at both the locations. Single Plant Progenies produced wide range for grain yield plant^{-1} (Fig. 4.1.88a and b). The experiment conducted at NARC exhibited that SPP only could be a breeding methodology for improving grain yield in this hybrid, whereas at FJ both SSD and SPP were equally good. Bulk Method did not give positive segregation; hence this method can not be utilized in this hybrid. Table 4.1.10 shows 60% plant for grain yield in F_2 at NARC followed by F_3 where 58% plant progenies were superior to MP at NARC.

4.1.9 Harvest Index

Harvest index a ratio between biological yield and economic yield, and for most of the grain crops, high harvest index is an established criterion for selection. It has a great importance in any field crop. In the present study the experiments were conducted under rainfed conditions at both the locations. Since the plants may not have attained full vegetative growth, harvest index was slightly higher as compared to report earlier. This could have been also due to parental effect in some cases. High mean yield in the harvest index range from 35.01 to >55 in SPP at FJ was observed in cross 9025/Mash 1 (Table 4.1.11). High mean grain yield was observed in BM and SSD in harvest index range interval 45.01 – 50.0 but low as compared to SPP at the same location. High mean grain

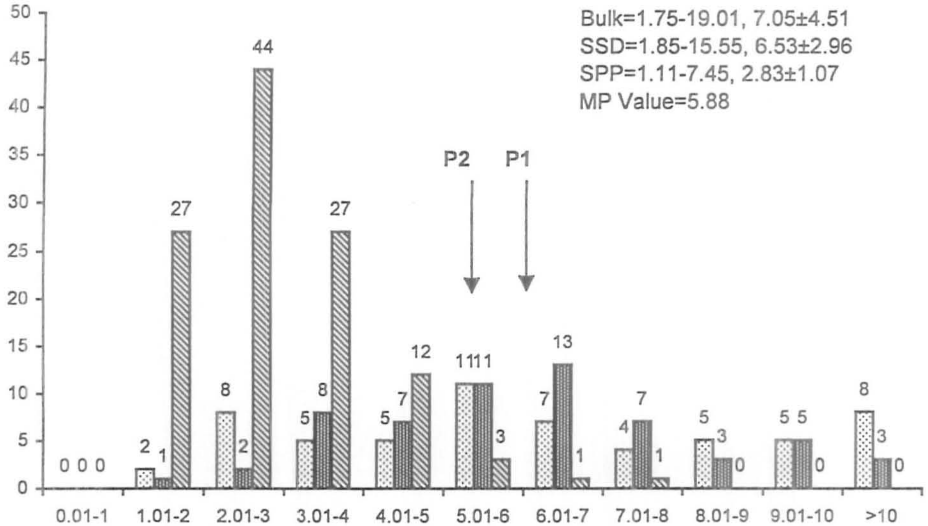


Fig. 4.1.86a. Comparison of three breeding methods for grain yield plant^{-1} in 9020/9012 of blackgram at FJ

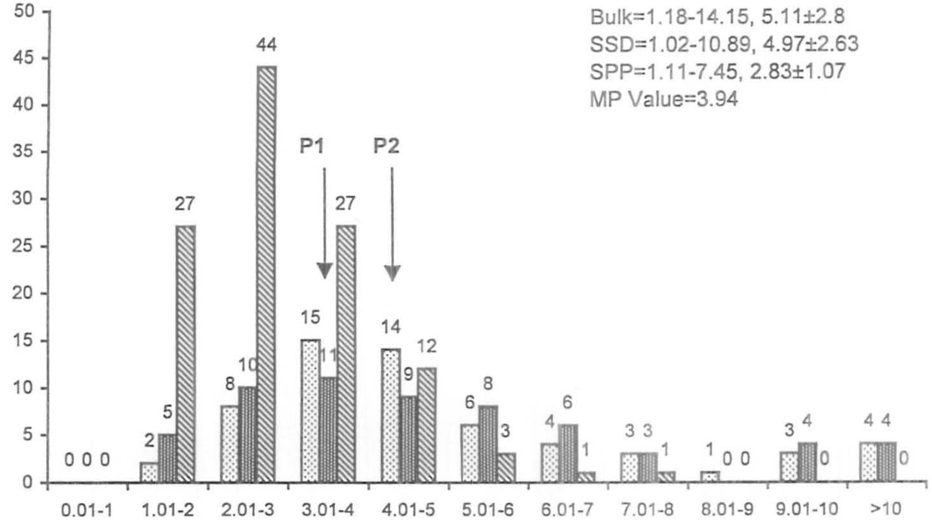


Fig. 4.1.86b. Comparison of three breeding methods for grain yield plant^{-1} in Mash 1/9020 of blackgram at NARC

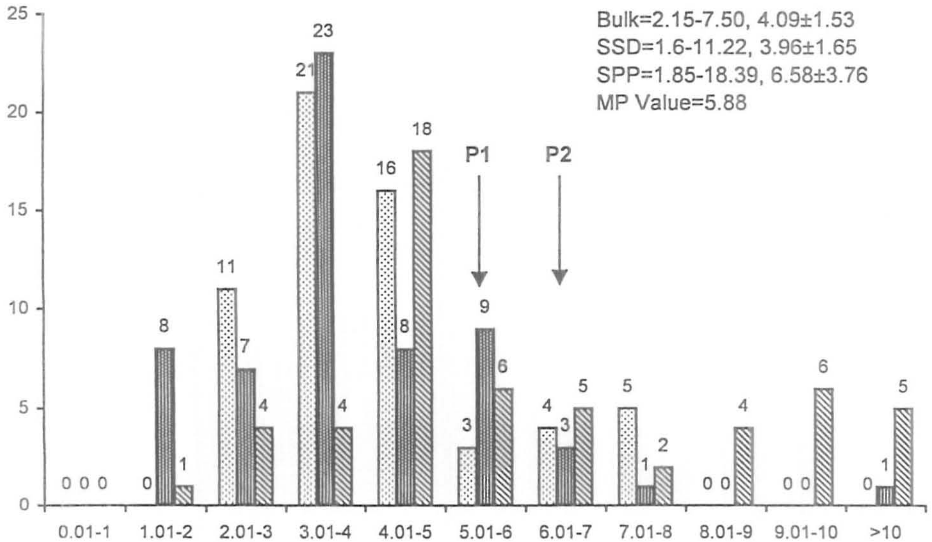


Fig. 4.1.87a. Comparison of three breeding methods for grain yield plant^{-1} in 9012/9020 of blackgram at FJ

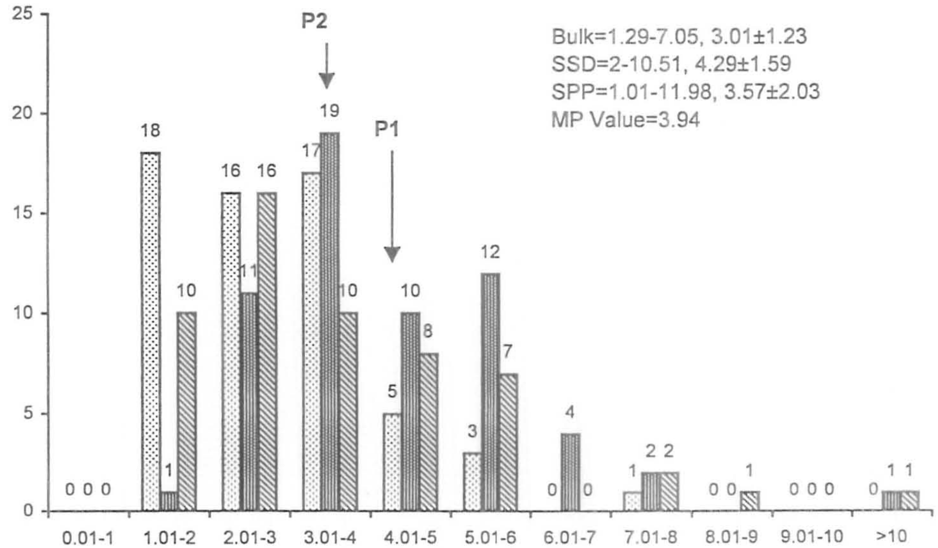


Fig. 4.1.87b. Comparison of three breeding methods for grain yield plant^{-1} in 9012/9020 of blackgram at NARC

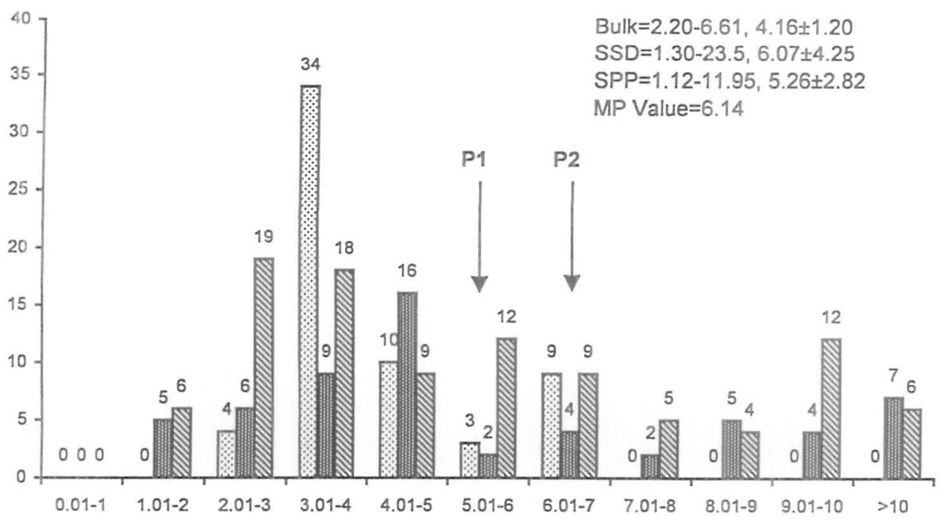


Fig. 4.1.88a. Comparison of three breeding methods for grain yield plant^{-1} in 9025/9026 of blackgram at FJ

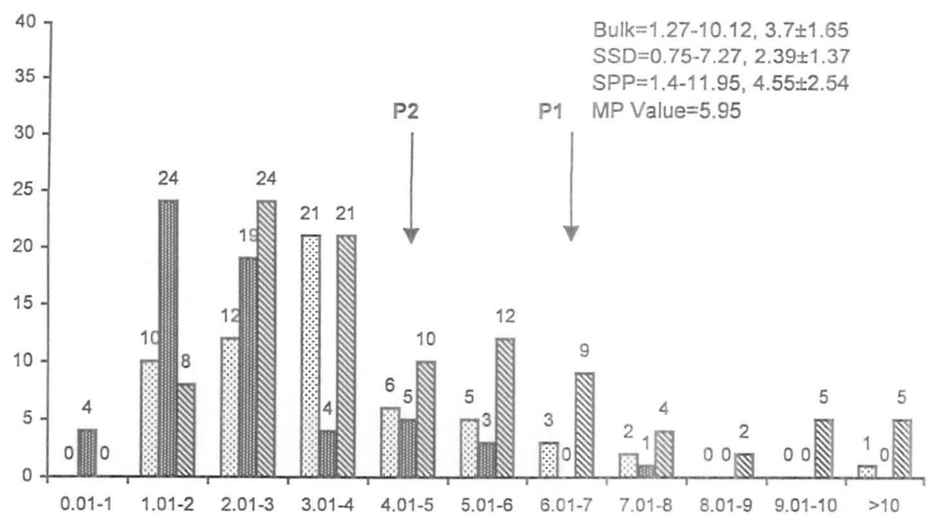


Fig. 4.1.88b. Comparison of three breeding methods for grain yield plant^{-1} in 9025/9026 of blackgram at NARC

Table 4.1.10: Number of plants and their percentage over mid parents value in grain yield plant^{-1} in 11 crosses at two locations.

Gen.	Location	Br. M.	M P Value	No. of sample collected	No. of plants over MP	%age over MP	M P Value	No. of sample collected	No. of plants over MP	%age over MP	M P Value	No. of sample collected	No. of plants over MP	%age over MP
			9025/Mash 1				Mash 3/Mash 1				Mash 3/9026			
F_2	NARC	SPP	9.18	30	12	40.00	10.1	30	18	60.00	8.88	30	18	60.00
F_3	NARC	SPP	6.89	50	11	22.00	7.91	50	13	26.00	5.16	50	31	62.00
F_4	NARC	SPP	5.78	145	35	24.14	4.37	160	108	67.50	4.54	120	54	45.00
F_4	FJ	SPP	5.15	145	85	58.62	5.42	160	128	80.00	6.41	120	69	57.50
F_4	FJ	BM	5.15	60	10	16.67	5.42	60	9	15.00	6.41	60	6	10.00
F_4	NARC	BM	5.78	60	0	0.00	4.37	60	22	36.67	4.54	60	4	6.67
F_4	FJ	SSD	5.15	60	9	15.00	5.42	60	28	46.67	6.41	60	5	8.33
F_4	NARC	SSD	5.78	60	18	30.00	4.37	60	35	58.33	4.54	60	33	55.00
			Mash 1/9026				9012/9025				9020/Mash 3			
F_2	NARC	SPP	8.98	30	18	60.00	9.34	30	15	50.00	9.81	30	9	30.00
F_3	NARC	SPP	6.31	50	14	28.00	4.96	50	25	50.00	5.60	50	11	22.00
F_4	NARC	SPP	5.07	105	40	38.10	5.48	100	38	38.00	3.71	70	30	42.86
F_4	FJ	SPP	5.69	105	52	49.52	5.59	100	91	91.00	6.17	70	53	75.71
F_4	FJ	BM	5.69	60	5	8.33	5.59	60	8	13.33	6.17	60	0	0.00
F_4	NARC	BM	5.07	60	4	6.67	5.48	60	0	0.00	3.71	60	23	38.33
F_4	FJ	SSD	5.69	60	10	16.67	5.59	60	26	43.33	6.17	60	10	16.67
F_4	NARC	SSD	5.07	60	35	58.33	5.48	60	22	36.67	3.71	60	43	71.67
			9020/Mash 1				Mash 1/9020				9020/9012			
F_2	NARC	SPP	9.91	30	24	80.00	9.91	30	18	60.00	10.07	30	6	20.00
F_3	NARC	SPP	6.75	50	13	26.00	6.75	50	11	22.00	4.82	25	50	50.00
F_4	NARC	SPP	4.24	55	23	41.82	4.24	55	29	52.73	3.94	115	19	16.52
F_4	FJ	SPP	5.44	55	45	81.82	5.44	55	21	38.18	5.88	115	3	2.61
F_4	FJ	BM	5.44	60	24	40.00	5.44	60	35	58.33	5.88	60	30	50.00
F_4	NARC	BM	4.24	60	44	73.33	4.24	60	42	70.00	3.94	60	35	58.33
F_4	FJ	SSD	5.44	60	25	41.67	5.44	60	36	60.00	5.88	60	32	53.33
F_4	NARC	SSD	4.24	60	44	73.33	4.24	60	35	58.33	3.94	60	38	63.33
			9012/9020				9025/9026							
F_2	NARC	SPP	10.07	30	6	20.00	7.96	30	18	60.00				
F_3	NARC	SPP	6.82	50	5	10.00	4.14	50	29	58.00				
F_4	NARC	SPP	3.94	55	20	36.36	5.95	100	26	26.00				
F_4	FJ	SPP	5.88	55	25	45.45	6.14	100	30	30.00				
F_4	FJ	BM	5.88	60	9	15.00	6.14	60	9	15.00				
F_4	NARC	BM	3.94	60	9	15.00	5.95	60	6	10.00				
F_4	FJ	SSD	5.88	60	5	8.33	6.14	60	22	36.67				
F_4	NARC	SSD	3.94	60	32	53.33	5.95	60	1	1.67				

yield was observed in SSD (5.39g) and SPP (4.90g) in harvest index range 40.01 – 50.0 at NARC. High range in harvest index in case of SSD and SPP was observed at FJ, whereas at NARC a low range coupled with high frequency in the harvest index range 45.01 – 50.0 was recorded for SPP where 95 plant progenies were evaluated (Fig. 4.1.89a and b).

In the hybrid Mash 3/Mash 1, harvest index ranged from 35.01 to 40.00 demonstrated better performance in BM and SSD at low rainfall area, i.e., FJ, whereas at NARC high harvest index was quite appropriate for improving grain yield and it was evident that BM could not prove its worth in improving grain yield, whereas, SSD and SPP gave reasonably desirable segregants at FJ (Table 4.1.11). This hybrid performed better in SPP and SSD at FJ, while all the three methods could be equally important at NARC. This might be due to more selection pressure in case of SPP at FJ. A wide range in all the three breeding methods were observed at NARC whereas, at FJ Single Seed Descent did not produce any plant with very high harvest index (Fig. 4.1.90a and b).

The hybrid Mash 3/9026 observed high harvest index range in SPP at FJ and at NARC, all the breeding methods possessed wide range for harvest index (Fig. 4.1.91a and b). However, maximum plant progenies fall in the range of 40.01 to 50 at both the locations. Table 4.1.11 indicated that maximum mean grain yield of 13.27 and 8.85g coupled with high variance (σ^2) was observed in SPP at both the locations in this cross. It is important to note that more than 10g grain yield plant^{-1} is considered high in blackgram. Therefore, these progenies need re-evaluation carefully in the following generations. Single Seed Descent and BM also produced enough mean grain yield in range of 35.01 to 55. However, the harvest index range from 40.01 to over 55 observed in SPP was more valid at both the locations in this cross.

While comparing breeding methods for cross Mash 1/9026, high range of harvest index was observed at both the locations (Fig. 4.1.92a and b). Bulk Method and SSD produced comparatively a low plant frequency at both the locations. This hybrid yielded maximum mean grain yield of 10.13g in SPP at FJ and in SSD (7.18 and 7.01g) at NARC in the range of 40.01 – 50 and 50.01 to 55, respectively (Table 4.1.11). Overall results observed in this hybrid revealed harvest index range of 35.01 to 55, was better in SSD and SPP breeding methods at both the locations.

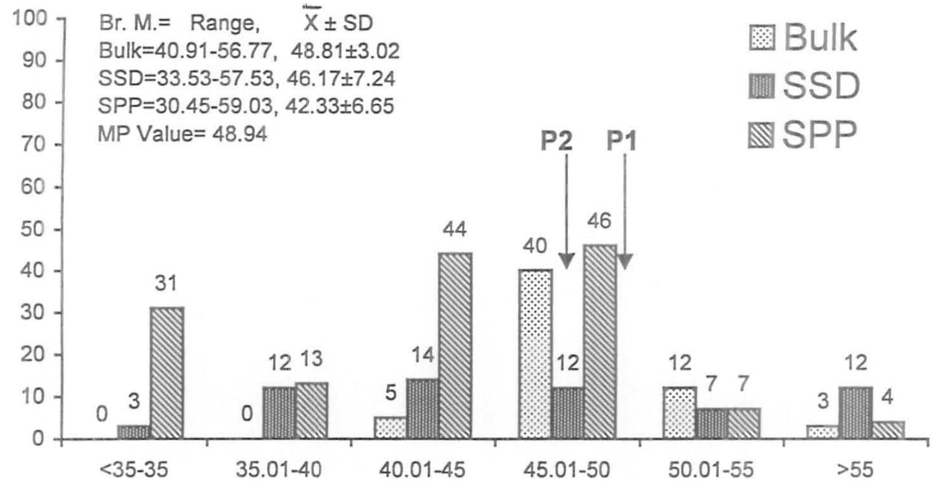


Fig. 4.1.89a. Comparison of three breeding methods for harvest index plant^{-1} (%) in 9025/Mash 1 of blackgram at FJ

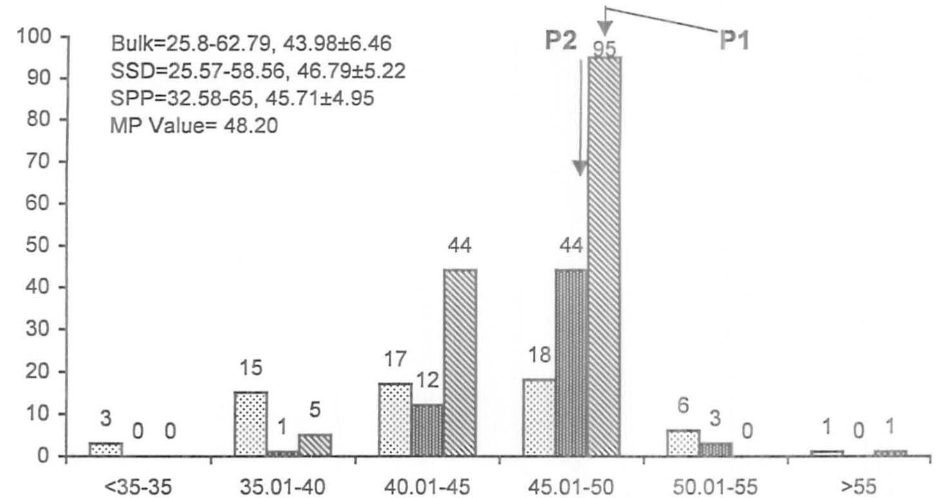


Fig. 4.1.89b. Comparison of three breeding methods for harvest index plant^{-1}(%) in 9025/Mash 1 of blackgram at NARC

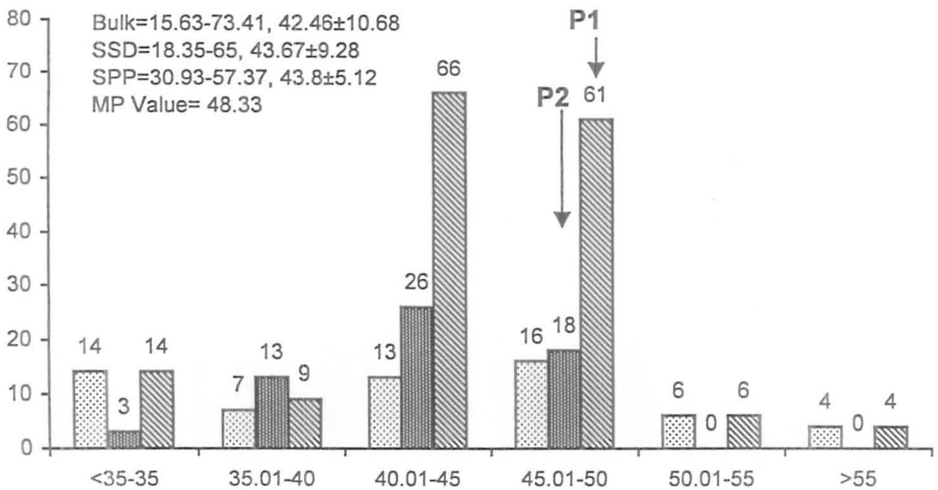


Fig. 4.1.90a. Comparison of three breeding methods for harvest index plant^{-1} (%) in Mash 3/Mash 1of blackgram at FJ

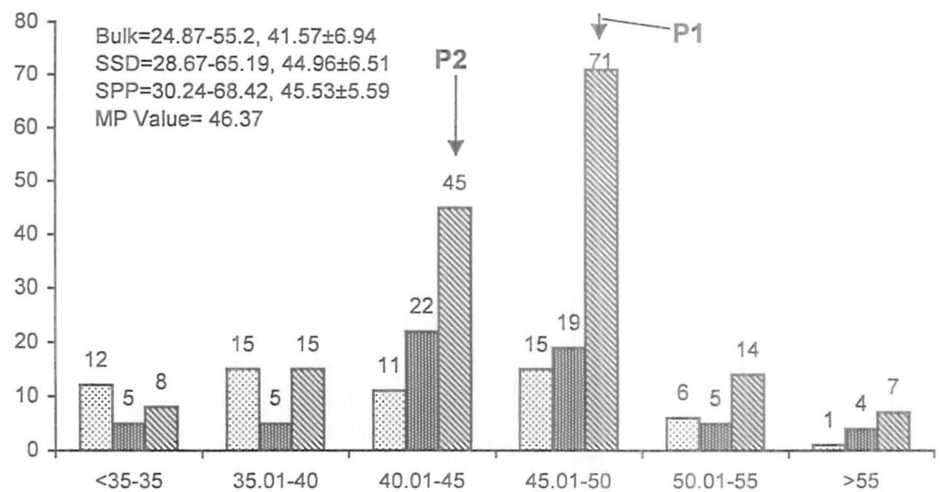


Fig. 4.1.90b. Comparison of three breeding methods for harvest index plant^{-1} (%) in Mash 3/Mash 1 of blackgram at NARC

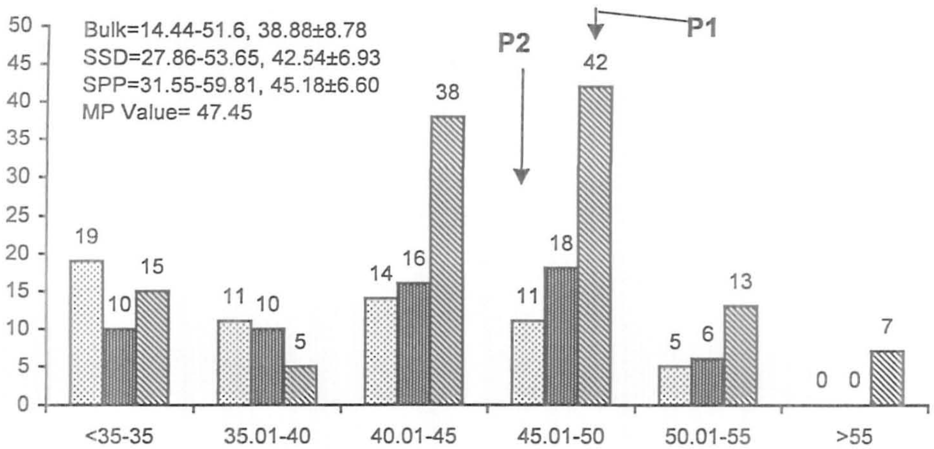


Fig. 4.1.91a. Comparison of three breeding methods for harvest index plant[1] (%) in Mash 3/9026 of blackgram at FJ

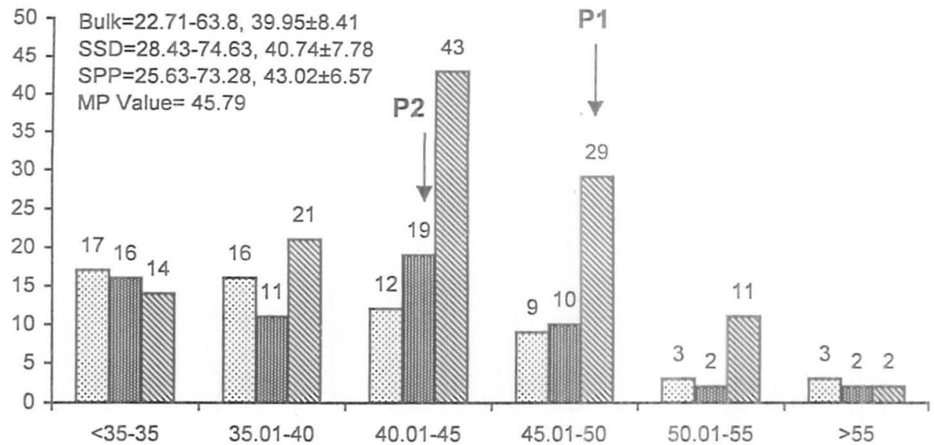


Fig. 4.1.91b. Comparison of three breeding methods for harvest index plant[1] (%) in Mash 3/9026 of blackgram at NARC

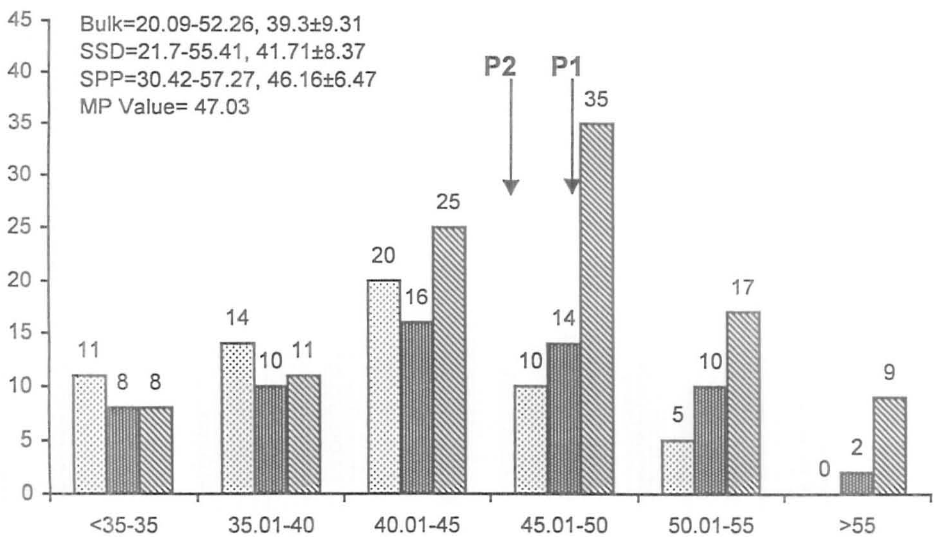


Fig. 4.1.92a. Comparison of three breeding methods for harvest index plant[1] (%) in Mash 1/9026 of blackgram at FJ

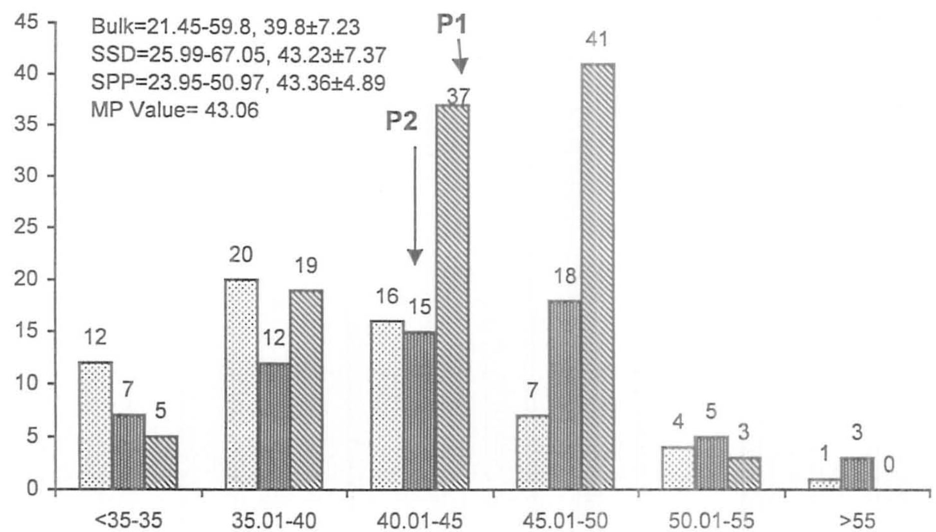


Fig. 4.1.92b. Comparison of three breeding methods for harvest index plant[1] (%) in Mash 1/9026 of blackgram at NARC

The hybrid 9012/9025 observed maximum plant frequency in the harvest index range of 40.01 – 50 in SPP at both the locations (Fig. 4.1.93a and b). However, wide range was observed in SPP at NARC. Single Seed Descent produced better harvest index range at FJ. While discussing the harvest index range with the mean grain yield, it was observed that maximum mean grain yield in SPP (13.55g) was observed in range of 35.01 – 40 at NARC and it was followed by 9.49±4.30 in the range of 45.01 – 50 (Table 4.1.11). Single Seed Descent also gave better mean grain yield at NARC in harvest index range of 35.01 to 50. However, at NARC, Single Plant Progenies and SSD produced better mean grain yield in range of 40.01 to 50.

The hybrid 9020/Mash 3 produced maximum plant frequency in range of 40.01 to 50 at FJ and from 45.01 to 55 at NARC in SPP (Fig. 4.1.94a and b). In general, this hybrid gave narrow range at both the locations especially at FJ, where SPP did not give segregation at both extremes. It was also observed that high mean grain yield (9.64 and 8.38g) was produced in the harvest index range from 35.01 – 40 and from 45.01 – 50 in SPP at FJ (Table 4.1.11). This hybrid gave better performance at FJ; hence desirable plant progenies could be isolated for this hybrid for low rainfall area. Bulk Method at FJ and SPP at NARC were unable to produce high grain yield in any harvest index range.

The cross 9020/Mash 1 revealed the highest plant frequency in SPP ranging from 45.01 to 50 at both the locations although at FJ high harvest index was not observed (Fig. 4.1.95a and b). All the three breeding methods produced maximum plant frequency in the range of 40.01 – 50 at FJ, while at NARC, SSD and BM exhibited high frequency in the same range. In this cross high mean grain yield was observed in range of 40.01 – 55 in BM and SPP breeding methods at both the locations (Table 4.1.11). In SSD, up to 50 harvest index range was better for high yield at FJ. Its reciprocal cross (Mash 1/9020) revealed maximum plant progenies toward lower side of the harvest index as compared to their parental values at FJ, while at NARC normal distribution was observed in all the breeding methods. However, at NARC maximum segregants were observed at higher side the mid parent values. Maximum plant frequency (37) was observed in SPP in the range of 45.01 to 50 at NARC (Fig. 4.1.96a and b). This hybrid revealed higher grain yield of 10.75g in the range of 45.01 – 50 at FJ in BM, where same method produced 9.56g in the range of 35.01 – 40 at NARC (Table 4.1.11). It is important to note that this hybrid gave better performance by Bulk Method at both the locations.

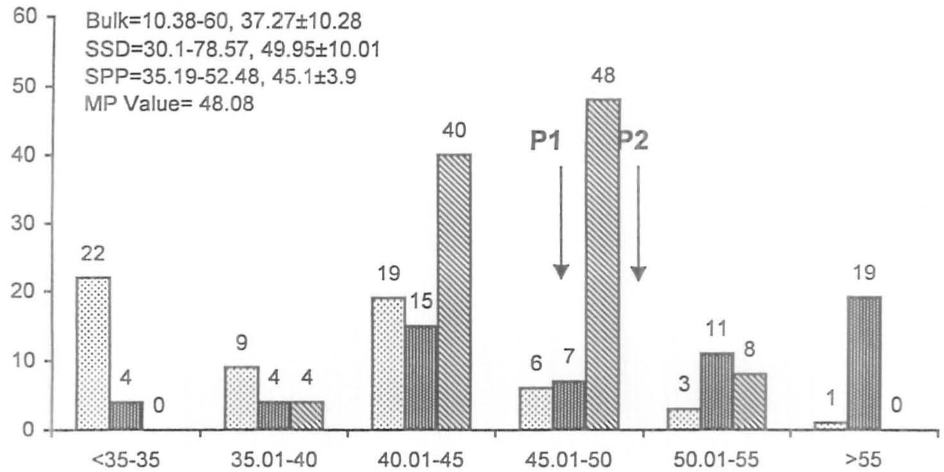


Fig. 4.1.93a. Comparison of three breeding methods for harvest index plant[-1] (%) in 9012/9025 of blackgram at FJ

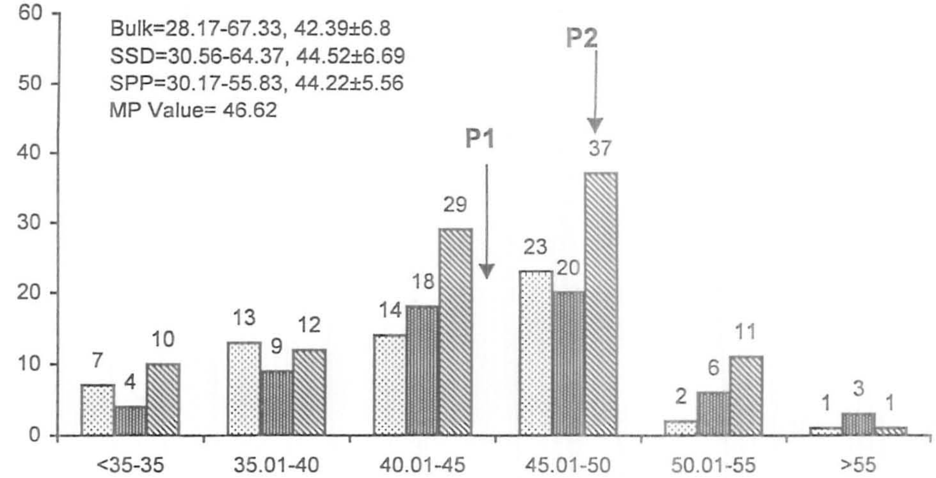


Fig. 4.1.93b. Comparison of three breeding methods for harvest index plant[-1] (%) in 9012/9025 of blackgram at NARC

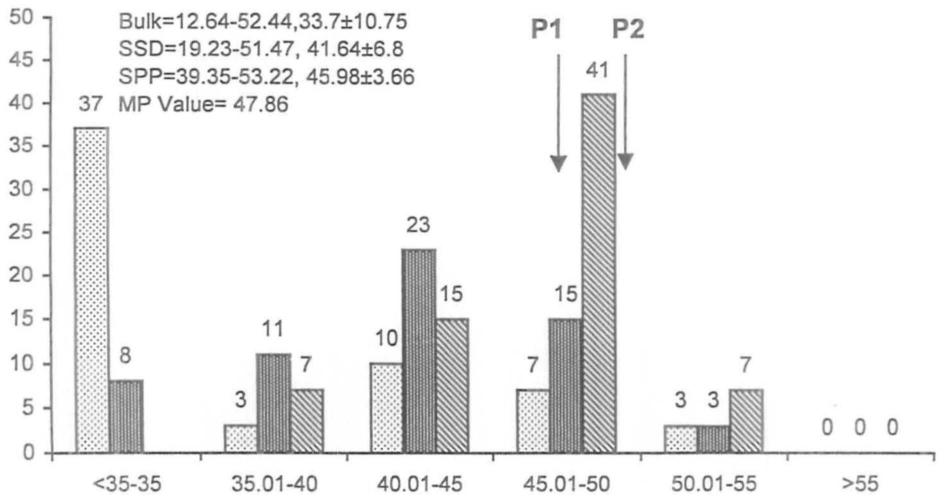


Fig. 4.1.94a. Comparison of three breeding methods for harvest index plant[-1] (%) in 9020/Mash 3 of blackgram at FJ

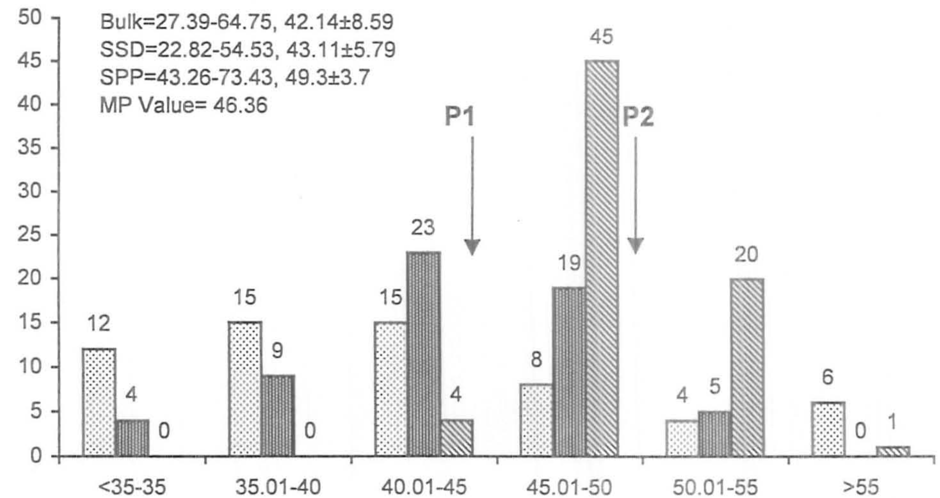


Fig. 4.1.94b. Comparison of three breeding methods for harvest index plant[-1] (%) in 9020/Mash 3 of blackgram at NARC

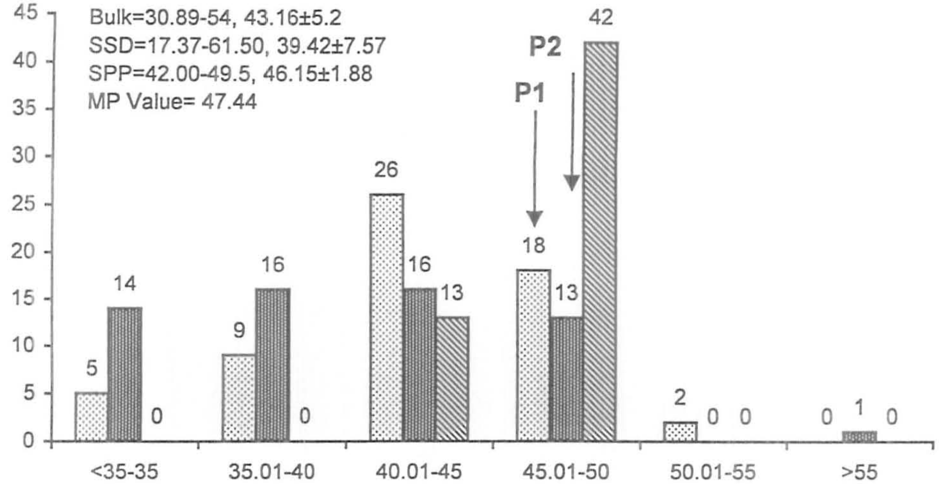


Fig. 4.1.95a. Comparison of three breeding methods for harvest index plant[-1] (%) in 9020/Mash 1 of blackgram at FJ

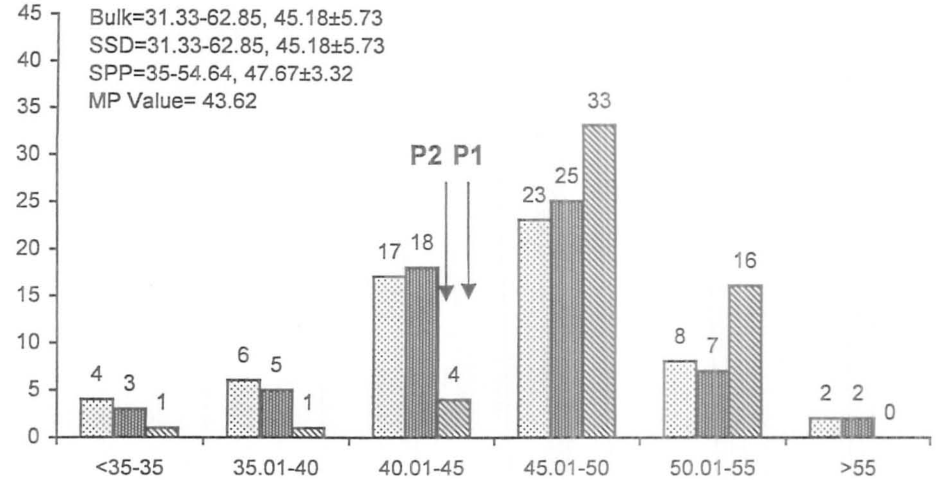


Fig. 4.1.95b. Comparison of three breeding methods for harvest index plant[-1] (%) in 9020/Mash 1 of blackgram at NARC

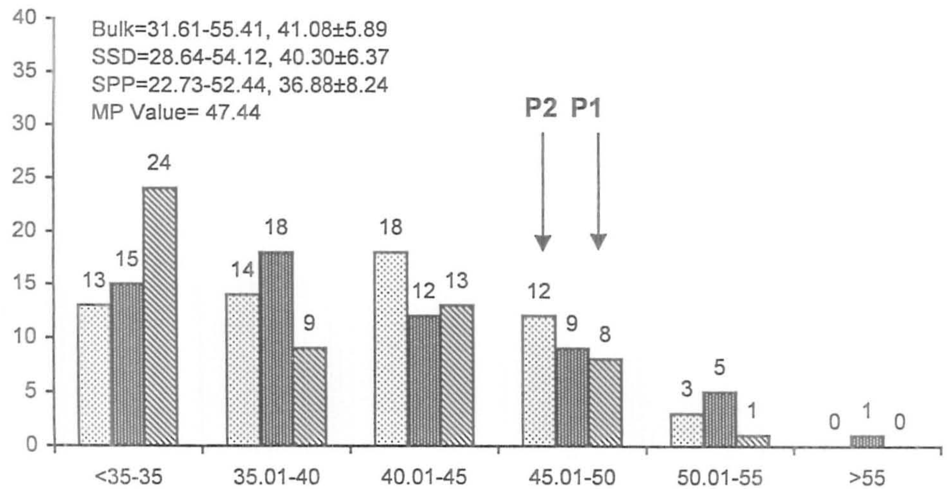


Fig. 4.1.96a. Comparison of three breeding methods for harvest index plant[-1] (%) in Mash 1/9020 of blackgram at FJ

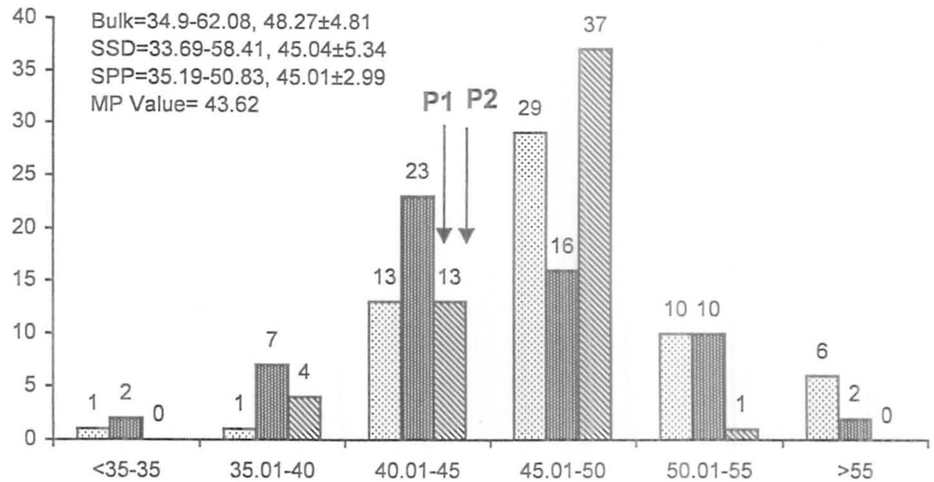


Fig. 4.1.96b. Comparison of three breeding methods for harvest index plant[-1] (%) in Mash 1/9020 of blackgram at NARC

The cross 9020/9012 observed high frequency in harvest index range of 40.01 to 50 in SPP at both the locations (Fig. 4.1.97a and b). However, wide range was observed in BM and SSD at both the locations. While discussing the mean grain yield according to harvest index class interval, maximum mean grain yield (10.68g) in harvest index range of 45.01 – 50 in BM and it was followed by 8.82g grain yield in SPP, (Table 4.1.11). At NARC, the harvest index range of 45.01 – 55 gave high mean grain yield in all the breeding methods.

Reciprocal hybrid (9012/9020) observed high plant frequency in SPP in two different ranges i.e., up to 35 at FJ and from 40.01 to 45 at NARC (Fig. 4.1.98a and b). Bulk Method and SSD gave wide harvest index range coupled with low frequency at both the locations. More logical results were achieved in all the breeding methods at NARC for high grain yield. High mean grain yield 8.71g and 8.82g were observed in SPP in the range of 40.01 – 45 and 45.01 – 50, respectively at FJ (Table 4.1.11).

The hybrid 9025/9026 demonstrated high plant frequency in SPP at both the locations (Fig. 4.1.99a and b). Bulk Method and SSD produced wide range at both the locations. While discussing the mean grain yield with harvest index range, it was observed that maximum mean grain yield (8.28g) coupled with high variance (6.53) was observed in SSD in the range of 45.01 – 50 at FJ (Table 4.1.11). Single Plant Progenies also produced high grain yield in the range of 35.01 to 50 at both the locations.

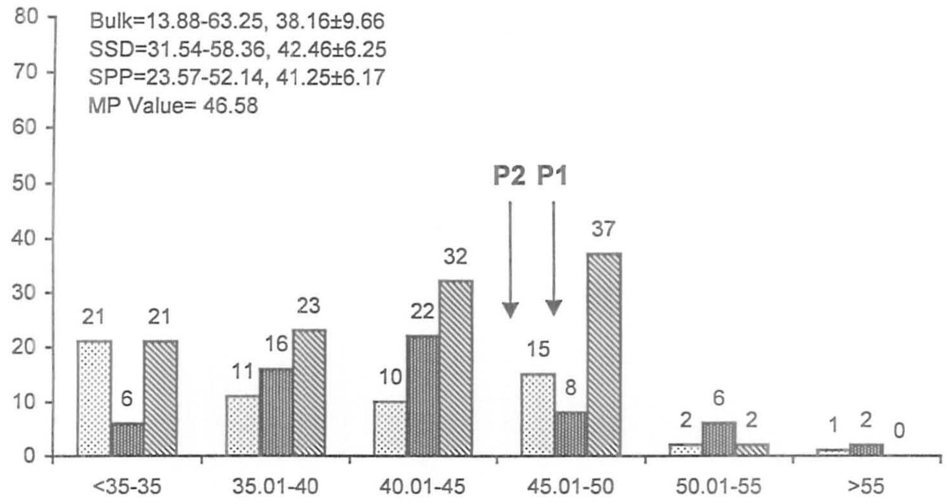


Fig. 4.1.97a. Comparison of three breeding methods for harvest index plant[-1] (%) in 9020/9012 of blackgram at FJ

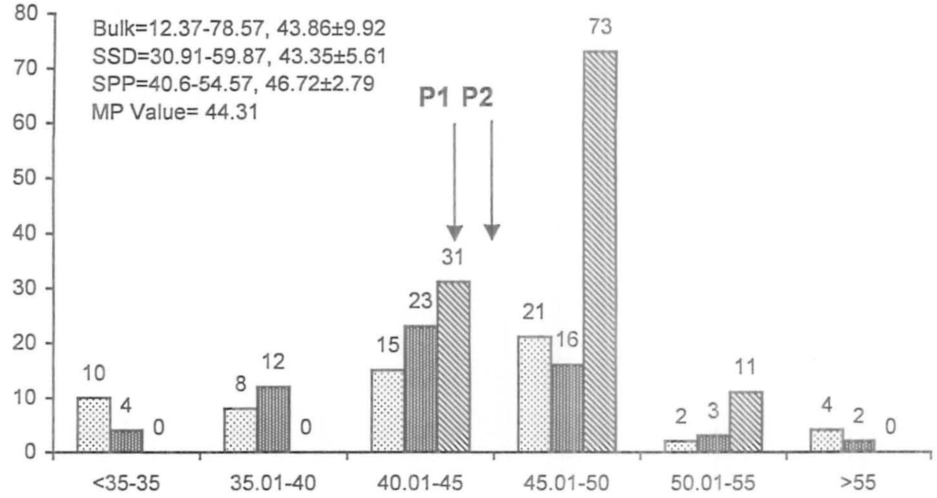


Fig. 4.1.97b. Comparison of three breeding methods for harvest index plant[-1] (%) in 9020/9012 of blackgram at NARC

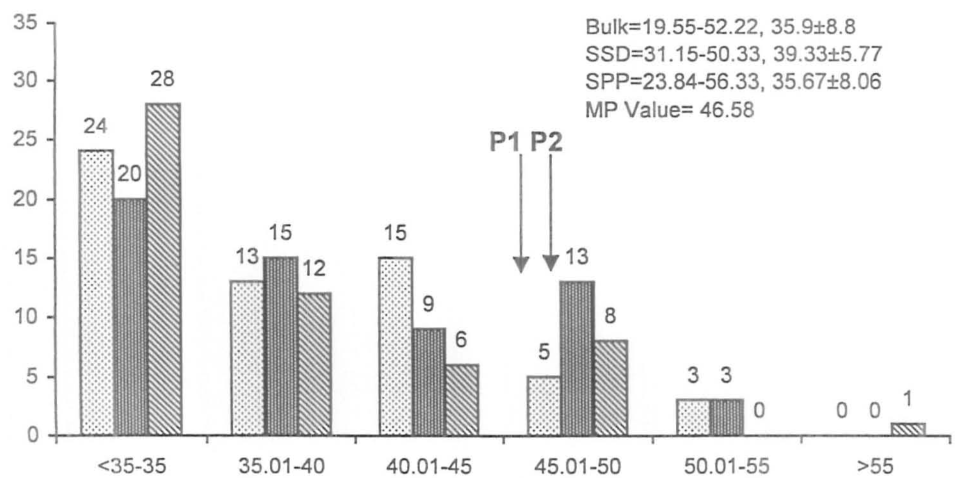


Fig. 4.1.98a. Comparison of three breeding methods for harvest index plant[-1] (%) in 9012/9020 of blackgram at FJ

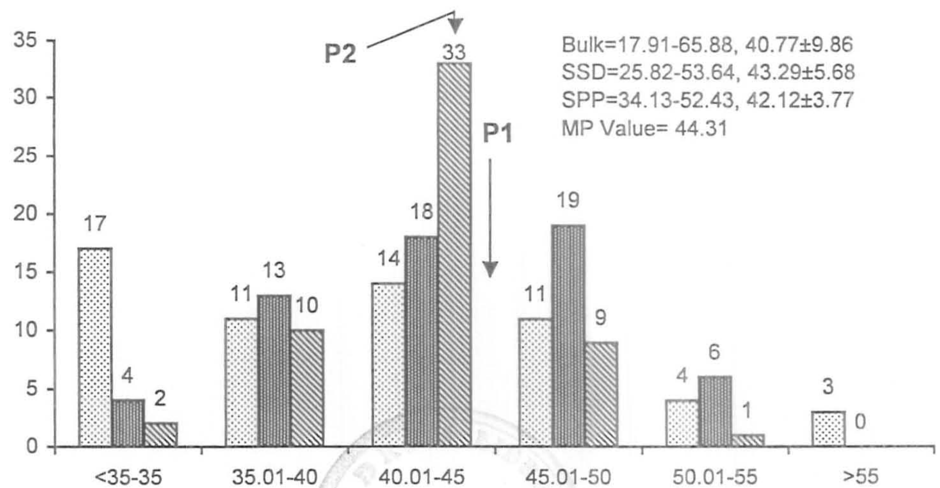


Fig. 4.1.98b. Comparison of three breeding methods for harvest index plant[-1] (%) in 9012/9020 of blackgram at NARC

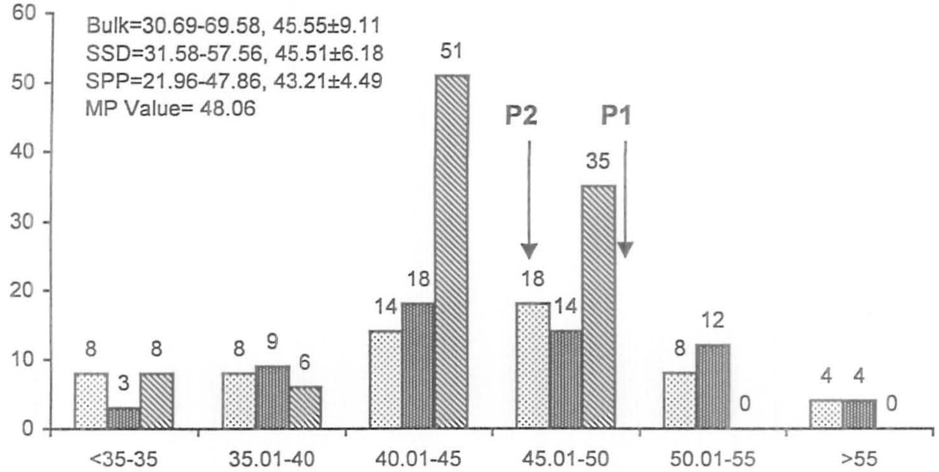


Fig. 4.1.99a. Comparison of three breeding methods for harvest index plant⁻¹ (%) in 9025/9026 of blackgram at FJ

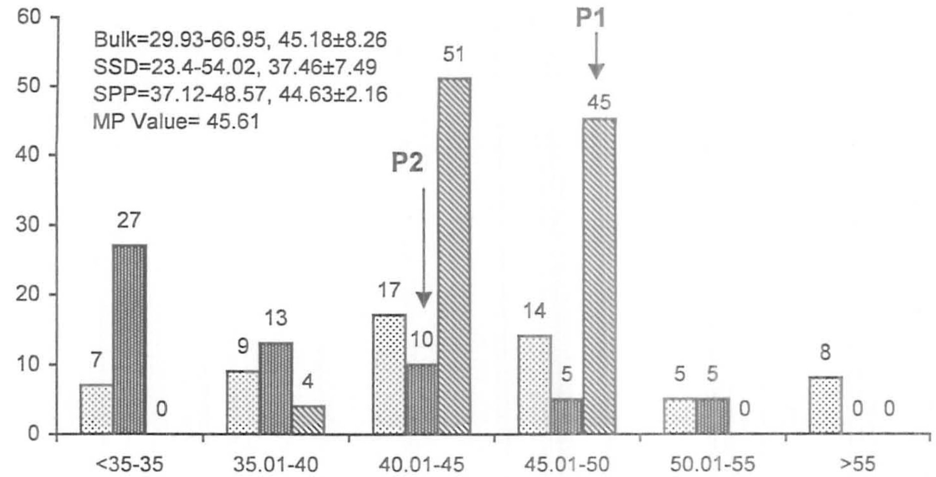


Fig. 4.1.99b. Comparison of three breeding methods for harvest index plant⁻¹ (%) in 9025/9026 of blackgram at NARC

Table 4.1.11: Mean and Standard Deviation of grain yield according to harvest index class interval in three breeding methods in F_4 at FJ and NARC.

Cross	Class Interval	FJ			NARC		
		BM	SSD	SPP	BM	SSD	SPP
9025/Mash 1	<35 – 35	-	2.58±0.46	3.80±1.22	2.42±1.37	-	2.90±0.0
	35.01– 40	-	2.82±1.65	8.61±2.58	2.68±0.95	4.40±2.10	3.86±1.79
	40.01 – 45	3.22±2.12	3.29±0.85	7.23±2.11	2.79±1.23	5.39±2.51	4.66±2.03
	45.01 – 50	3.95±3.09	5.56±2.45	6.02±2.12	2.34±0.85	4.78±1.77	4.90±2.05
	50.01 – 55	3.92±3.02	3.88±0.36	7.31±0.04	2.67±0.72	4.72±1.67	4.78±1.41
	>55	1.71±0.05	4.36±0.60	8.17±1.36	5.23±0.0	5.33±0.16	3.26±1.16
Mash 3/Mash 1	<35 – 35	3.15±1.77	4.31±1.62	6.90±2.48	3.00±1.44	4.45±2.11	5.63±1.55
	35.01– 40	4.70±1.69	7.01±2.58	8.82±2.94	4.21±2.08	5.73±2.40	4.46±1.56
	40.01 – 45	4.27±1.78	5.42±1.28	8.88±3.41	3.91±1.66	5.32±2.41	6.01±2.64
	45.01 – 50	4.25±1.34	6.37±1.79	8.89±3.75	5.67±2.90	5.33±1.95	5.72±2.45
	50.01 – 55	3.74±0.17	5.08±1.06	10.52±6.45	5.30±3.30	4.22±1.50	5.51±1.61
	>55	2.62±0.46	3.52±0.55	12.45±0.01	5.52±0.0	4.78±0.71	6.41±1.05
Mash 3/9026	<35 – 35	3.30±1.23	3.03±1.39	9.51±4.36	2.80±1.36	4.22±1.71	3.64±1.20
	35.01– 40	2.53±0.47	5.10±1.46	4.45±0.30	2.51±1.07	5.55±1.97	4.24±2.02
	40.01 – 45	4.92±4.06	4.55±1.37	8.35±3.47	2.69±1.01	5.73±2.95	5.49±2.56
	45.01 – 50	5.70±3.10	3.59±0.89	7.94±2.56	3.81±1.56	4.92±2.64	4.52±1.76
	50.01 – 55	4.48±1.74	4.26±0.31	4.95±0.34	2.37±0.31	6.09±3.11	4.79±2.54
	>55	-	-	13.27±7.70	2.82±0.35	5.16±1.36	8.85±6.14
Mash 1/9026	<35 – 35	2.58±0.55	3.92±2.85	8.51±2.73	2.81±1.49	3.69±1.70	3.92±1.80
	35.01– 40	2.67±0.12	4.96±3.29	5.24±0.77	3.11±1.06	4.69±1.68	3.43±1.53
	40.01 – 45	4.22±0.81	2.94±0.79	5.20±1.60	3.06±1.02	7.18±2.29	4.46±1.86
	45.01 – 50	3.56±1.80	4.23±2.15	6.94±1.70	3.53±0.87	7.01±3.42	5.21±1.91
	50.01 – 55	5.42±0.65	4.20±1.75	10.13±6.07	3.10±0.74	5.87±1.35	5.60±3.61
	>55	-	4.76±0.06	4.35±1.35	5.98±0.0	6.34±2.37	-
9012/9025	<35 – 35	3.85±1.65	2.47±0.49	-	2.28±0.86	5.07±3.30	3.05±1.37
	35.01– 40	3.12±0.64	7.13±4.47	13.55±0.01	2.94±1.06	4.47±1.93	3.90±2.03
	40.01 – 45	4.57±2.04	7.25±3.66	8.92±2.96	3.26±0.74	5.44±2.69	5.60±2.54
	45.01 – 50	3.03±1.56	7.70±3.17	9.49±4.30	3.17±0.98	5.44±2.54	5.40±1.68
	50.01 – 55	2.95±0.10	4.25±1.77	9.35±3.21	2.31±0.28	3.64±0.69	5.13±1.05
	>55	2.70±0.10	4.72±1.88	-	1.01±0.0	5.56±3.34	3.35±0.0

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Cross	Class Interval	FJ			NARC		
		BM	SSD	SPP	BM	SSD	SPP
9020/Mash 3	<35 – 35	2.13±0.37	2.28±0.64	-	2.71±0.87	3.79±2.83	-
	35.01– 40	3.25±0.01	6.14±1.94	9.64±0.01	3.19±0.78	5.70±1.90	-
	40.01 – 45	3.06±0.73	4.25±1.94	6.85±1.35	3.62±1.77	5.33±2.44	2.91±0.91
	45.01 – 50	3.20±1.53	3.70±1.56	8.38±2.67	3.85±1.36	5.03±1.99	3.75±1.61
	50.01 – 55	2.23±0.14	4.92±0.06	7.21±1.36	3.84±0.88	4.06±1.15	3.33±1.25
	>55	-	-	-	3.56±1.87	-	2.57±0.0
9020/Mash 1	<35 – 35	4.24±1.49	7.39±5.64	-	4.05±1.28	3.54±1.60	1.05±0.0
	35.01– 40	4.02±0.79	4.56±2.48	-	5.67±2.52	5.20±2.81	3.60±0.0
	40.01 – 45	5.86±2.63	4.92±2.31	10.05±1.73	6.01±1.96	7.11±2.58	2.99±1.54
	45.01 – 50	6.42±3.04	6.73±1.09	8.07±3.68	6.89±2.77	6.04±2.39	5.01±2.80
	50.01 – 55	3.79±0.01	-	-	7.75±2.73	5.94±2.86	3.85±1.97
	>55	-	-	-	5.62±3.21	8.14±5.64	-
Mash 1/9020	<35 – 35	5.65±0.59	5.41±1.33	4.95±1.75	6.98±0.0	2.98±1.11	-
	35.01– 40	5.50±1.76	7.61±2.19	4.29±0.39	9.56±0.0	4.73±2.05	3.55±1.39
	40.01 – 45	7.78±2.28	5.33±2.30	6.57±2.09	5.44±2.36	6.37±3.50	4.25±1.78
	45.01 – 50	10.75±6.04	6.21±3.59	5.96±1.19	6.69±3.15	6.21±3.23	5.08±2.41
	50.01 – 55	4.71±0.01	7.09±2.40	8.39±0.0	5.03±2.60	4.79±2.26	3.05±0.0
	>55	-	-	-	5.31±2.23	7.83±6.61	-
9020/9012	<35 – 35	4.55±2.47	3.68±1.62	6.04±4.60	4.13±2.28	5.67±3.39	-
	35.01– 40	5.90±2.22	7.32±3.35	5.26±2.27	4.61±1.11	4.34±2.56	-
	40.01 – 45	8.12±3.60	7.05±2.98	8.71±2.82	4.01±1.24	4.86±2.74	2.62±1.09
	45.01 – 50	10.68±6.32	6.69±2.92	8.82±0.32	6.45±3.80	5.25±2.65	2.92±1.04
	50.01 – 55	6.22±0.09	6.09±0.97	-	6.97±2.43	5.66±3.16	2.84±1.29
	>55	7.59±0.0	3.56±0.01	-	4.75±2.25	5.36±1.22	-
9012/9020	<35 – 35	3.27±0.80	3.61±2.26	6.04±4.60	2.21±0.82	3.62±1.57	3.06±0.10
	35.01– 40	4.19±1.73	3.46±0.96	5.26±2.27	2.88±1.36	3.85±1.11	3.59±3.18
	40.01 – 45	4.46±1.64	5.15±1.28	8.71±2.82	3.52±0.99	4.34±1.54	3.62±1.59
	45.01 – 50	4.85±0.64	4.48±1.03	8.82±0.32	3.21±1.46	4.54±2.06	3.64±2.45
	50.01 – 55	7.05±0.01	3.01±0.01	-	3.86±1.04	4.79±0.89	2.01±0.0
	>55	-	-	6.76±0.0	2.87±0.88	-	-
9025/9026	<35 – 35	4.23±0.81	3.42±0.92	2.12±0.76	3.10±1.00	1.98±1.12	-
	35.01– 40	2.98±0.83	3.57±2.38	4.87±3.32	3.05±1.12	2.84±1.43	6.08±3.51
	40.01 – 45	4.16±0.96	5.42±3.00	5.95±2.80	3.97±1.94	3.0±1.73	4.71±2.78
	45.01 – 50	4.30±1.24	8.28±6.53	5.03±2.60	3.73±1.52	2.62±0.94	4.23±2.15
	50.01 – 55	3.70±0.0	6.72±3.55	-	3.76±1.99	1.98±1.62	-
	>55	6.61±0.01	6.88±1.88	-	4.28±2.01	-	-

4.1.10 Correlation Study

Simple correlation analysis of grain yield with other 8 traits was carried out for all the three breeding methods at both the locations with the help of MS Excel (Table 4.1.12). Grain yield was positively correlated with plant height in most of the cases in SSD and SPP breeding methods at both the locations in almost all crosses. Two hybrids (Mash 3/9026 and 9020/9012) exhibited positive correlation with similar magnitude at both locations and for 3 breeding methods. Hence, these populations could be exploited under wide range of environmental conditions adopting any breeding methods. Branches plant^{-1} was significantly correlated with grain yield in all the crosses in SPP at both locations. Similar results were observed for SSD except for three crosses (Mash 3/Mash 1, 9020/9012 and 9025/9026) where branches were non-significant. In Bulk Method grain yield also showed positive and highly significant correlation with branches except in case of 9025/9026 at both the locations.

Number of pods plant^{-1} and biological yield plant^{-1} were positively correlated with grain yield in all crosses at both the locations. 5 pod length and seed pod^{-5} were inconsistent for correlation with grain yield that indicated the utilization of these traits for individual hybrid to improve grain yield in breeding method.

100 seed weight and harvest index were observed negatively correlated with grain yield in most of the hybrids at both the locations. However, five crosses (Mash 1/9026, 9020/Mash 3, 9020/Mash 1, Mash 1/9020 and 9025/9026) showed positive correlation with grain yield in different breeding method. Therefore, while breeding for high grain yield, 100 seed weight and harvest index specific hybrids could be selected through application of suitable breeding method. Mash 3/Mash 1 showed significant correlation for 100 seed weight in SSD and SPP breeding method at FJ showing their worth with grain yield. Harvest index showed positive correlation with grain yield in crosses, Mash 1/9026, 9020/Mash 3, 9012/9020 and 9025/9026 in Bulk Method at both the locations. So this trait can be improved at either location.

Table 4.1.12: Correlation of grain yield with other 8 traits in 11 crosses at FJ and NARC locations.

Crosses	Location	PH			Br/P			Pods/Plant			BY		
		Bulk	SSD	SPP	Bulk	SSD	SPP	Bulk	SSD	SPP	Bulk	SSD	SPP
9025/Mash 1	FJ	0.40**	0.60**	0.58**	0.63**	0.71**	0.67**	0.92**	0.84**	0.70**	0.90**	0.94**	0.93**
	NARC	0.01 ns	0.21 ns	0.23**	0.55**	0.51**	0.36**	0.65**	0.79**	0.87**	0.90**	0.96**	0.97**
Mash3/Mash 1	FJ	0.22 ns	-0.26 ns	0.42**	0.40**	0.09 ns	0.47**	0.47**	0.80**	0.73**	0.86**	0.77**	0.95**
	NARC	0.40**	0.37**	0.09 ns	0.76**	0.68**	0.61**	0.79**	0.88**	0.89**	0.95**	0.59**	0.95**
Mash 3/9026	FJ	0.35**	0.47**	0.37**	0.61**	0.71**	0.81**	0.86**	0.87**	0.86**	0.90**	0.90**	0.97**
	NARC	0.50**	0.61**	0.19*	0.56**	0.52**	0.65**	0.81**	0.85**	0.89**	0.88**	0.93**	0.93**
Mash 1/9026	FJ	0.14 ns	0.61**	0.20*	0.66**	0.78**	0.63**	0.80**	0.93**	0.78**	0.68**	0.91**	0.92**
	NARC	0.21 ns	0.56**	0.38**	0.26*	0.53**	0.59**	0.77**	0.85**	0.89**	0.86**	0.94**	0.94**
9012/9025	FJ	0.59**	0.68**	-0.01 ns	0.65**	0.70**	0.56**	0.85**	0.94**	0.89**	0.80**	0.96**	0.96**
	NARC	0.21 ns	0.57**	0.43**	0.31*	0.62**	0.70**	0.42**	0.93**	0.92**	0.89**	0.95**	0.96**
9020/Mash 3	FJ	0.00 ns	0.44**	0.06 ns	0.28*	0.61**	0.40**	0.85**	0.83**	0.41**	0.26*	0.94**	0.96**
	NARC	0.05 ns	0.48**	0.30*	0.42**	0.58**	0.61**	0.71**	0.90**	0.83**	0.83**	0.96**	0.99**
9020/Mash 1	FJ	0.68**	0.28*	0.48**	0.67**	0.71**	0.83**	0.80**	0.85**	0.79**	0.96**	0.82**	0.90**
	NARC	0.21 ns	0.21 ns	0.37**	0.52**	0.52**	0.53**	0.82**	0.82**	0.87**	0.95**	0.95**	0.99**
Mash 1/9020	FJ	0.38**	0.28*	-0.10 ns	0.58**	0.42**	0.31**	0.83**	0.84**	0.71**	0.97**	0.90**	0.74**
	NARC	0.27 ns	0.66**	-0.05 ns	0.36**	0.56**	0.53**	0.91**	0.85**	0.96**	0.98**	0.97**	0.99**
9020/9012	FJ	0.36**	0.25*	0.31**	0.66**	0.17 ns	0.53**	0.93**	0.83**	0.77**	0.91**	0.97**	0.93**
	NARC	0.32**	0.69**	0.31**	0.76**	0.60**	0.59**	0.85**	0.82**	0.77**	0.90**	0.95**	0.99**
9012/9020	FJ	0.20 ns	0.34**	0.67**	0.48**	0.76**	0.58**	0.92**	0.64**	0.79**	0.68**	0.95**	0.93**
	NARC	0.32*	-0.01 ns	0.62**	0.52**	0.42**	0.34**	0.80**	0.85**	0.89**	0.75**	0.90**	0.99**
9025/9026	FJ	0.18 ns	0.68**	0.53**	0.18 ns	0.88**	0.57**	0.57**	0.96**	0.89**	0.71**	0.98**	0.98**
	NARC	0.48**	0.49**	0.48**	-0.05 ns	0.60**	0.56**	0.61**	0.90**	0.84**	0.81**	0.94**	0.99**

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Crosses	Location	5PL			5PS			100 SW			HI		
		Bulk	SSD	SPP	Bulk	SSD	SPP	Bulk	SSD	SPP	Bulk	SSD	SPP
9025/Mash 1	FJ	0.28**	0.12^{ns}	0.43**	0.35**	0.49**	0.18^{ns}	0.09^{ns}	0.10^{ns}	-0.51^{ns}	-0.18^{ns}	0.40**	0.35**
	NARC	0.28**	0.34**	0.23**	0.16^{ns}	0.48**	0.17*	0.16^{ns}	0.04^{ns}	-0.09^{ns}	0.03^{ns}	0.01^{ns}	0.07^{ns}
Mash3/Mash 1	FJ	0.40**	-0.12^{ns}	0.27**	0.38**	0.12^{ns}	0.14^{ns}	-0.17^{ns}	0.39**	0.32**	0.09^{ns}	0.06^{ns}	0.22**
	NARC	0.48**	0.33**	0.04^{ns}	0.54**	0.38**	0.18*	-0.34**	-0.10^{ns}	-0.10^{ns}	0.38**	0.18^{ns}	0.09^{ns}
Mash 3/9026	FJ	-0.03^{ns}	0.49**	0.44**	0.24^{ns}	0.44**	0.29**	-0.35**	0.24^{ns}	0.28**	0.32**	-0.04^{ns}	0.19*
	NARC	0.40**	0.60**	0.30**	0.54**	0.55**	0.32**	0.05^{ns}	-0.05^{ns}	0.01^{ns}	0.12^{ns}	0.21^{ns}	0.24**
Mash 1/9026	FJ	0.64**	0.35**	0.45**	0.29**	0.36**	0.22*	0.07^{ns}	0.37**	0.06^{ns}	0.67**	0.05^{ns}	-0.01^{ns}
	NARC	0.46**	0.53**	0.47**	0.37**	0.51**	0.53**	0.07^{ns}	0.20^{ns}	-0.08^{ns}	0.28**	0.34**	0.29**
9012/9025	FJ	0.58**	0.13^{ns}	-0.01	0.29*	0.06^{ns}	0.00^{ns}	-0.15^{ns}	-0.40**	0.21*	-0.03^{ns}	-0.15^{ns}	0.03^{ns}
	NARC	0.34**	0.37**	0.50**	0.33**	0.41**	0.53**	0.23^{ns}	-0.23^{ns}	-0.35**	0.14^{ns}	0.01^{ns}	0.27**
9020/Mash 3	FJ	0.58**	0.41**	0.35**	0.46**	0.35**	0.36**	0.28*	0.23^{ns}	0.58**	0.50**	0.21^{ns}	0.07^{ns}
	NARC	0.32**	0.44**	0.38**	0.40**	0.47**	0.50**	0.12^{ns}	0.09^{ns}	0.12^{ns}	0.31*	0.07^{ns}	-0.04^{ns}
9020/Mash 1	FJ	0.32*	0.30*	0.14^{ns}	0.42**	0.21^{ns}	-0.03^{ns}	-0.72**	0.43**	-0.74^{ns}	0.14^{ns}	0.45**	-0.09^{ns}
	NARC	0.48**	0.48**	0.63**	0.13^{ns}	0.13^{ns}	0.67**	0.18^{ns}	0.18^{ns}	0.17^{ns}	0.18^{ns}	0.18^{ns}	0.09^{ns}
Mash 1/9020	FJ	0.32*	-0.07^{ns}	0.13^{ns}	0.27*	0.23^{ns}	0.45**	-0.31*	0.04^{ns}	0.07^{ns}	0.22^{ns}	0.13^{ns}	0.45**
	NARC	0.60**	0.53**	-0.15^{ns}	0.50**	0.44**	0.47**	-0.20^{ns}	-0.16^{ns}	0.67**	-0.17^{ns}	0.04^{ns}	0.13^{ns}
9020/9012	FJ	0.26^{ns}	0.15^{ns}	0.37**	0.36**	0.23^{ns}	0.45**	-0.01^{ns}	0.01^{ns}	0.03^{ns}	0.44**	-0.02^{ns}	0.26**
	NARC	0.49**	0.51**	0.37**	0.64**	0.46**	0.45**	-0.37**	0.16^{ns}	0.03^{ns}	0.19^{ns}	0.07^{ns}	0.00^{ns}
9012/9020	FJ	0.14^{ns}	0.15^{ns}	0.53**	0.38**	0.15^{ns}	0.60**	-0.13^{ns}	0.19^{ns}	-0.24^{ns}	0.52**	0.16^{ns}	0.34**
	NARC	0.47**	0.57**	0.51**	0.42**	0.51**	0.40**	-0.06^{ns}	0.27*	-0.16^{ns}	0.39**	0.26**	-0.18^{ns}
9025/9026	FJ	-0.03^{ns}	0.45**	0.67**	-0.01^{ns}	0.08^{ns}	0.67**	-0.33**	0.40**	0.55**	0.39**	0.25*	0.28**
	NARC	0.40**	0.57**	0.62**	0.31*	0.59**	0.64**	0.36**	-0.12^{ns}	0.45**	0.28**	0.18^{ns}	-0.11^{ns}

* and ** Significant at 0.05 and 0.01 percent probability level, respectively. ^{ns} stand for non-significant.

Experiment II

4.2 *Inheritance of Qualitative Traits*

4.2.1 *Pubescence*

Two hybrids, i. e., Mash 1/MM33-40 and Mash 3/Mash 1 were investigated for pubescence. Out of parents used in these crosses Mash 1 was glabrous, whereas others (MM 33-40 and Mash 3) were having hairs on plants. The allelic notion for this character was assigned as *HH* (dominant homozygous hairy); *Hh* (heterozygous hairy) and *hh* (homozygous recessive non-hairy). The F_1 plant were all having hairs for both the hybrids either female parent was kept pubescence or glabrous, suggesting *hh* alleles recessive to *HH, Hh* types. The F_2 segregation for these crosses showed 3:1 ratio that fit for goodness by χ^2 method (Table 4.21). This 3:1 ratio indicated the monogenic nature of this character.

Table 4.2.1: Segregation for pubescence in the F_2 population in blackgram.

Cross	Observation				
	Pubescence *(HH, Hh)*	Plant glabrous *(hh)*	Expected ratio	χ^2	P at 5%
Mash 1/MM 33-40	77	23	3:1	0.213	0.644
Mash 3 /Mash 1	83	24	3:1	0.376	0.539

χ^2 = Chi-square P= Probability level

4.2.2 *Pod colour*

Two crosses (Mash 1MM33-40 and 45726/MM33-40) gave segregation for pod colour. Two types of pod colour have been observed in blackgram germplasm, i.e., black and brown and these were assigned allelic notion *BB* (homozygous black); *Bb* (heterozygous black) and *bb* (recessive brown). Pod colour was recorded in F_1 and F_2 on the basis of black or brown colour and the data were analyzed for inheritance. Among parents used in the study, MM 33-40 was brown pod, whereas others had black pod colour. All the F_1 plants were observed as black pod colour for each hybrid which revealed the presence of dominance for black pod colour, whereas brown pods being recessive in blackgram. The F_2 population segregation in a 3:1 ratio for all the crosses which fit for goodness by χ^2 method with slight variation in probability (Table 4.2.2). This ratio indicated the monogenic nature of this character.

Table 4.2.2: Segregation for pod colour in the F_2 population in blackgram.

Cross	Observation				
	Black *(BB, Bb)*	Brown *(bb)*	Expected ratio	χ^2	P at 5%
Mash 1/MM 33-40	72	28	3:1	0.480	0.488
45726 /MM 33-40	54	18	3:1	0.665	0.412

X^2 = Chi-square P= Probability level

4.2.3 Seed coat colour

The observation on seed coat colour was taken at maturity in the crosses (Mash 1/MM33-40 and 45726/MM33-40). One parent (MM 33-40) produced green seed coat colour and hence it was used for hybridization with other contrasting parents. The allelic notion was given as *CC* (homozygous brown); *Cc* (Heterozygous brown) and *cc* (recessive green). The F_1 having brown seed coat colour with slightly diffused black spots for both the hybrid, either female parent was kept brown or green, suggesting the dominance of brown seed coat in nature, whereas green being recessive. The F_2 population segregated in a 3:1 ratio for both the crosses in which χ^2 did not fit well for 3:1 ratio (Table 4.2.3). This 3:1 ratio indicated the monogenic nature of seed coat colour in crop.

Table 4.2.3: Segregation for seed coat colour in the F_2 population in blackgram.

Cross	Observation				
	Brown *(CC, Cc)*	Green *(cc)*	Expected ratio	χ^2	P at 5%
Mash 1/MM 33-40	72	28	3:1	0.480	0.488
45726/MM 33-40	86	21	3:1	1.648	0.200

X^2 = Chi-square P= Probability level

4.2.4. Spots on seed coat

Presence or absence of spots on seed coat colour were observed on freshly harvested seeds and analysed for inheritance (Table 4.2.4). Allelic forms were assigned as *SS* (homozygous spots present); *Ss* (heterozygous spots present) and *ss* (recessive spots absent). The parental line MM 33-40 was without spots and green seeded. All the F_1 plants of two crosses (Mash 1/MM33-40 and 45726/MM33-40) were observed with spots for both either female parent was kept spotted or un-spotted which indicated the dominant nature of this character, whereas the un-spotted nature was recessive. The F_2 population segregated in a ratio of 3:1 for all the crosses which fit for goodness by χ^2 method with slight variation in probability. This 3:1 ratio revealed the presence of monogenic gene action for phenotypic expression on seed coat of blackgram.

Table 4.2.4: Segregation for spots on seed coat in the F_2 population in blackgram.

Cross	Observation				
	Present *(SS, Ss)*	Absent *(ss)*	Expected ratio	χ^2	P at 5%
Mash1 /MM 33-40	78	22	3:1	0.480	0.488
45726 /MM 33-40	53	19	3:1	1.251	0.174

χ^2 = Chi-square P= Probability level

4.2.5. Linkage analysis

Inheritance of qualitative characters revealed that single dominance gene was involved for pubescence (*HH, Hh*), seed coat colour (*CC, Cc*), seed spots (*SS, Ss*) and pod colour (*BB, Bb*). Further, analysis of linkage among these characters was carried out and the results regarding linkage loci are presented in Table 4.2.5. Three hybrids (Mash 1/MM33-40, Mash 1/45702 and 45726/MM33-40) were investigated for the linkage analysis among genetic markers in F_2 generation using the computer programme "LINKAGE 1" of Suiter *et al.*, (1983). This joint segregation of independent assortment revealed linkage for various characters pairs.

The hybrid Mash 1/MM33-40 revealed linkage of three characters pairs i.e., black pod colour vs seed coat colour producing 92% parental types, pod colour vs presence of spots on seed coat with 88% parental types and seed coat colour vs spots on seed that produced 94% parental type (Table 4.2.5).

Table 4.2.5: Joint segregation for four morphological markers in three F_2 populations in blackgram.

Hybrid	Number of plants/observations								
	Loci	-/-	-/+	+/-	+/+	χ^2	P	r	Parental type (%)
Mash1 /MM 33-40	*HH:BB*	6	17	14	63	0.692	0.406	0.43±0.08	69
	HH:CC	7	16	21	56	0.087	0.767	0.48±0.07	63
	HH:SS	7	16	15	62	1.238	0.266	0.42±0.08	69
	BB:CC	20	0	8	72	64.286	0.000	0.85±0.10	92
	BB:SS	15	5	7	73	40.924	0.000	0.14±0.09	88
	CC:SS	22	6	0	72	72.527	0.000	0.06±0.09	94
Mash 1/45702	*HH:BB*	3	75	19	111	5.977	0.014	0.25±0.06	54
45726/MM 33-40	*BB:CC*	21	0	33	18	9.882	0.002	0.34±0.10	54
	BB:SS	18	3	5	46	39.43	0.000	0.11±0.12	88
	CC:SS	19	35	4	14	1.043	0.307	0.41±0.10	45

-/- and +/+ are homologous recessive and homologous dominant, whereas, -/+ and +/- are heterozygous dominant. *HH*- denotes plant hairiness; *CC*- seed coat colour; *SS*- the spots present on seed coat and *BB*- black pod colour.

Experiment III

4.3 Heterosis Study

Table 4.3.1 indicated significant differences and total variance was attributed towards years, parents and their interaction for all the characters. The parents were evaluated over the years during generation enhancement but for individual parent low deviation and insignificant variation for replications indicated high magnitude of genetic purity although blackgram is highly sensitive to environmental changes. Analysis of variance for generations and hybrids showed significant differences ($P < 0.001$) for all the characters in case of generations, whereas for hybrids and interaction, branches were insignificant (Table 4.3.2). This source of variation and that of the generations represented high proportions of the total sum of squares.

The PCA showed that two factors gave eigen values greater than unity, whereas others were < 1, hence first two principal components were considered important in contributing variation amongst breeding material. First two components contributed 77% of the total variability (Table 4.3.3). All the characters were more contributed to first PC except harvest index that was more related to second component. All the variables except harvest index contributed positively to PC_1: thus this component is a weighted average of the characters. Figure 4.3.1 presents the eleven hybrids for four generations along with six parents that indicated a clear response for grouping especially F_1 and F_2, whereas other two generations were intermixed although a low level of separation was observed. From mean values and hybrid vigour (over mid and better parents) of all the hybrids and generations depending upon the best values for various characters are presented in Table 4.3.4. On the basis of results when combined for average performance and hybrid vigour, three hybrids; Mash 3/Mash 1, 9012/9025 and 9020/Mash 1 were observed better although later two could not perform better for F_3 (9012/9025) and F_3 & F_4 (9020/Mash 1). Most of the traits ranked top in later generations in these three hybrids. Although the hybrid, Mash 1/9020 gave the best performance for one or the other character in all the four generations but this performance could not be reflected in hybrid vigour except for vegetative traits in F_3 that might be due to involvement of epistasis or non-allelic interaction involved for various characters. To generalize the performance of various hybrids, scores were calculated for mean performance and hybrid vigour along with standard deviation for these two parameters (Fig. 4.3.2). The results presented in the Table 4.3.4 are in coordination with Figure 4.3.2. The hybrid, 9020/Mash 1 gave the best average performance on the basis of pooled generations and it was followed by the hybrids Mash 3/Mash 1 and Mash 1/9020. For heterotic performance, the hybrid 9012/9025 ranked top and followed by 9020/Mash 1 and Mash 3/Mash 1. The hybrids, 9025/Mash 1, Mash 3/9026, Mash 1/9026, 9020/Mash 3 and 9020/9012 were suggested to exclude for further evaluation as none of these could qualify the required level of average performance or hybrids vigour. The hybrids with high mean performance and hybrids vigour are expected to give better chance for selection to develop superior cultivars of blackgram.

Table 4.3.1:-Mean and Standard deviation (average of parent used in F_1-F_4) along with analysis of variance for six parents involved in 11 hybrids of blackgram.

Parents	Plant height	Branches $plant^{-1}$	Pods $plant^{-1}$	Pod length	Seeds pod^{-5}	100-seed weight	Biological yield $plant^{-1}$	Grain yield $plant^{-1}$	Harvest index
Mash 1	51.6±4.76	9.3±2.92	54.8±13.8	4.56±0.21	6.14±0.63	5.18±0.23	35.32±8.29	13.70±2.78	39.46±4.12
Mash 3	40.9±5.65	10.9±3.23	52.1±12.43	4.46±0.21	5.82±0.55	4.60±0.24	26.76±6.79	11.34±2.77	44.56±7.33
9012	50.1±7.63	8.5±3.78	50.4±22.16	4.42±0.25	5.86±0.59	4.85±0.25	24.61±9.89	9.31±3.80	40.49±4.14
9020	48.5±5.09	9.9±2.74	46.8±16.78	4.60±0.26	6.28±0.41	4.98±0.30	34.58±11.46	10.37±2.81	38.06±6.26
9025	47.6±6.51	7.7±4.13	38.2±15.78	4.56±0.19	6.08±0.43	4.69±0.27	22.92±9.12	8.34±4.13	40.73±5.55
9026	43.3±5.20	9.6±2.05	44.8±9.35	4.78±0.27	6.48±0.48	4.84±0.27	23.80±5.98	9.75±2.35	41.52±4.3
MS (Rep.)	98.09*	15.89	363.25	0.56	1.68	0.14	139.67	11.72	32.22
MS (Parents)	808.73**	57.93**	1697.08**	3.58**	15.02**	2.03**	1471.91**	169.47**	230.97**
MS (Year)	397.76**	157.94**	1162.54**	2.52**	11.77**	2.96**	841.02**	401.66**	130.36**
MS (PxY)	1409.80**	62.31**	829.58**	5.65**	9.33**	2.77**	760.67**	109.89**	247.34**
Error	60.48	14.43	292.40	0.45	2.04	0.10	105.55	11.71	43.95
CV (%)	16.52	40.57	35.71	6.56	10.45	6.43	36.69	32.69	16.25

* Significant at $P < 0.05$ and **- Significant at $P < 0.01$, CV- Coefficient of variability.

Table 4.3.2: Analysis of Variance (Mean square and probability) from F_1 to F_4 generation of blackgram.

S.O.V	d.f	Plant height	Branches plant^{-1}	Pods plant^{-1}	Pod length	Seeds pod^{-5}	100-seed weight	Biological yield plant^{-1}	Grain yield plant^{-1}	Harvest index
Replication	2	8.563	56.47	50.04	0.19	0.26	0.02	111.51	6.30	0.29
Generation	3	4099.25**	9239.84**	6458.09**	9.37**	33.97**	1.93**	23914.92**	2936.35**	846.69**
Hybrids	10	359.71**	48.24	1664.48**	0.84**	3.21**	1.27**	650.17**	56.48**	55.40**
Generation x Variety	30	161.52**	60.84	856.57*	0.49**	2.57**	0.26**	436.21**	37.65**	43.58**
Error	86	21.976	71.66	492.21	0.09	0.40	0.04	193.03	19.10	11.72
CV (%)		9.78	38.88	24.69	3.15	4.70	4.36	20.38	39.78	8.46

* -Significant at $P < 0.05$ and **- Significant at $P < 0.01$,

CV- Coefficient of variability.

Table 4.3.3:-Principal Components (PCs) for yield and its component in four segregating populations in *Vigna mungo*

	PC_1	PC_2
Eigen value	5.4	1.5
Proportion of σ^2	59.5	17.5
Cumulative σ^2	59.5	77.0
Factors		
Plant height (cm)	0.49	-0.77
Branches/ plant	0.89	0.37
Pods/plant	0.94	0.26
Pod length (cm)	0.70	0.14
Seeds/pod	0.76	0.02
Seed weight (g)	0.54	-0.18
Biomass (g)	0.97	0.09
Grain yield (g)	0.96	0.22
Harvest index (%)	-0.64	0.67

Table 4.3.4:- Mean values, heterosis (over mid, better and top parents) ranked top three in various hybrids for four generations of blackgram

Hybrid	Generation	Best mean performance	Best hybrid vigour	
			Mid Parent	Better Parents
9025/Mash 1	F_1	-	Br	Br
	F_2	-	-	-
	F_3	-	-	-
	F_4	HI	-	-
Mash 3/Mash 1	F_1	PL	-	-
	F_2	Pods	Br, Pods, BY	Pods
	F_3	Br, Pods, GY	Br, SPP, HI	HI
	F_4	BY, GY	Pods, BY, GY	Br, BY, GY
Mash 3/9026	F_1	-	PH	PH
	F_2	HI	-	-
	F_3	-	-	-
	F_4	SPP	Br, SPP	SPP
Mash 1/9026	F_1	HI	-	-
	F_2	-	-	-
	F_3	PL, 100SW	-	-
	F_4	PL	-	-
9012/9025	F_1	PH	PL, SPP, 100SW, GY, HI	PL, SPP, 100SW, GY HI
	F_2	SPP	PH, SPP	PH, SPP
	F_3	-	-	GY
	F_4	Pods	-	Pods
9020/Mash 3	F_1	-	-	-
	F_2	-	-	-
	F_3		-	PL, SPP
	F_4	HI	-	-
9020/Mash 1	F_1	BY, Br, Pods, GY	Pods, BY,	BY
	F_2	GY, 100SW	100SW, GY, HI	100SW, GY, HI
	F_3	-	100SW	100SW
	F_4	-	PL, HI	PL, HI
Mash 1/9020	F_1	100SW,	-	-
	F_2	BY, Br,	-	-
	F_3	BY	-	Br, BY
	F_4	100SW	-	-
9020/9012	F_1	-	-	Pods
	F_2	PL	-	-
	F_3	-	PL	-
	F_4	-	-	-
9012/9020	F_1	SPP	-	-
	F_2	-	-	-
	F_3	PH,HI	-	-
	F_4		Br	-
9025/9026	F_1	PH	-	-
	F_2	-	PL	PL, BY
	F_3	-	PH, Pods, BY, GY	PH, Pods
	F_4	PH, Br	PH	PH

PH- Plant height, Br-Branches, PL-Pod length, SPP-Seeds per pod, 100SW-100 seeds weight, BY-Biological Yield, GY-Grain Yield, and HI-Harvest Index.

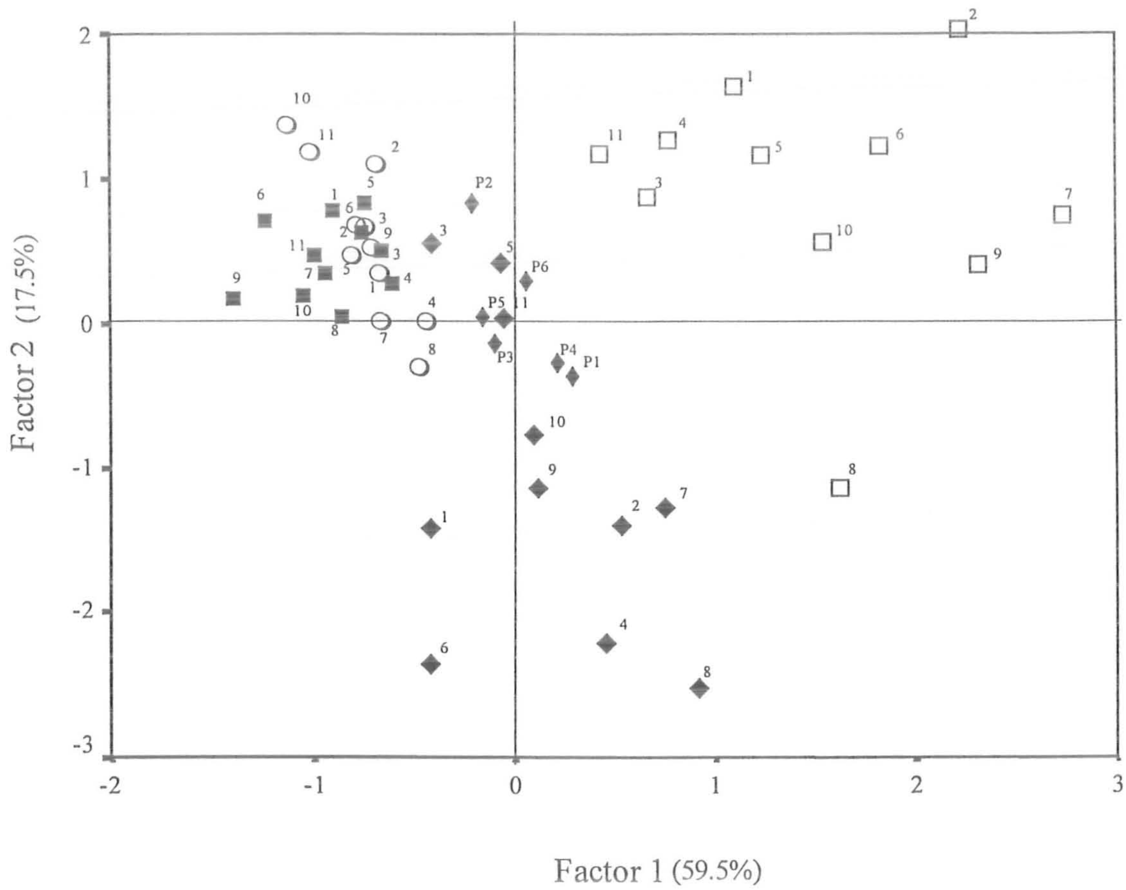

Fig. 4.3.1: Scattered diagram representing 11 hybrids evaluated for four generations based on two factors. The symbols represent as, □-F_1, ◆-F_2, ○- F_3, ■ -F_4 generations and ♦- parents. The hybrids are referred in Table 4.3.4.

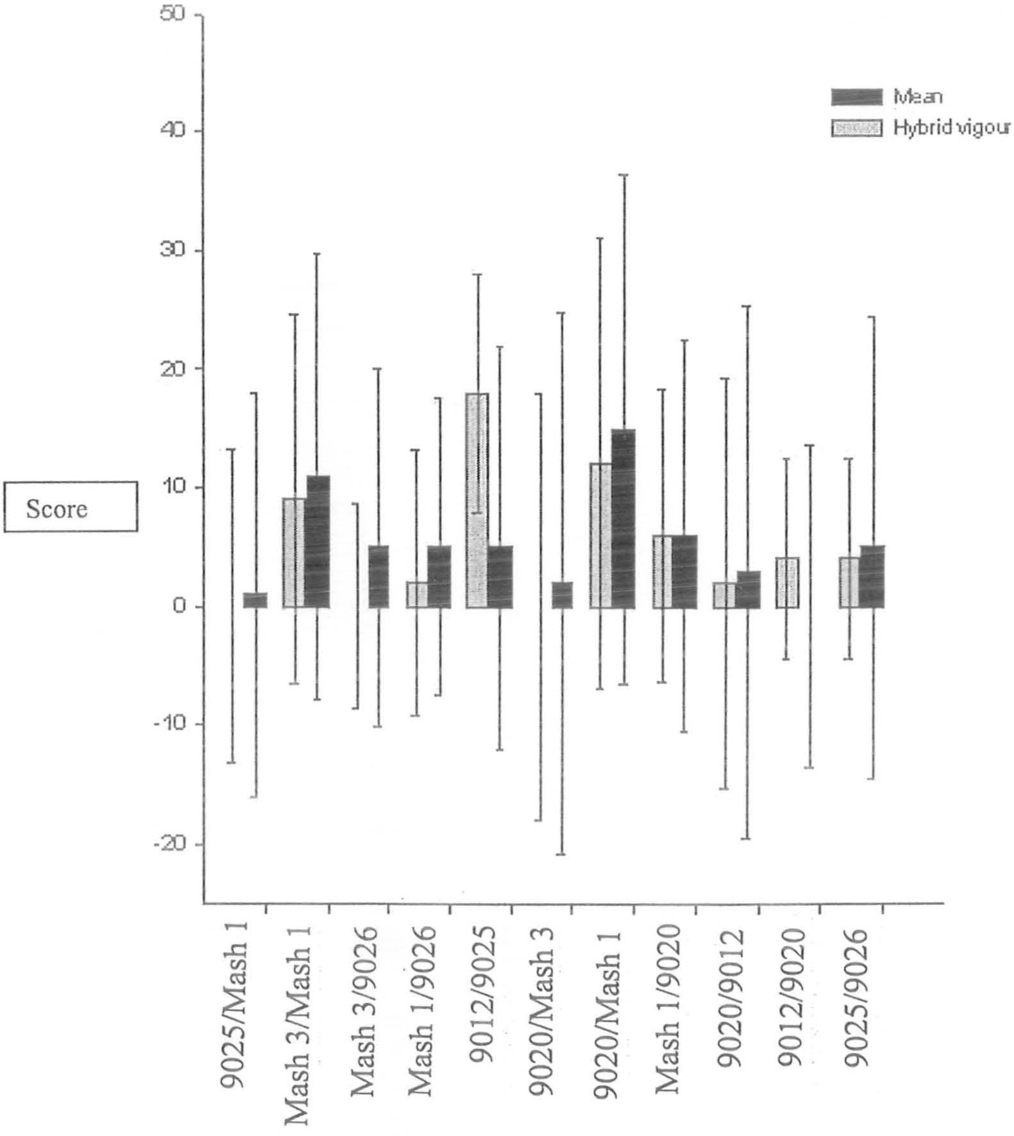

Fig. 4.3.2: Score for hybrid vigour and mean performance of 11crosses based on four generations evaluated for nine characters.

DISCUSSION

DISCUSSION

5.1 *Breeding Methods*

Worth of any breeding programs depends on simplicity and the promise of rapid crop improvement, as no breeding system is completely perfect for general use. Qualset and Vogt (1980) suggested that the range of choice in breeding methods should be wide and available to meet different situations. Choice of an effective selection procedure for handling the segregating populations is the most important decision a plant breeder has to take.

In the present study, breeding methods varied for their utility although SPP and SSD were equally good but due to simplicity SSD was observed better for branches, pods number, pod length, seeds pod^{-1}, 100 seed weight and grain yield. Efficiency of the conventional selection procedures has been questioned on many grounds (Gill 1980; Verma and Kumar, 1980). Goulden (1939) proposed a system in which visual selection is eliminated and in each generation, one or two seeds are taken at random from each plant to produce the next generation.

The Single Seed Descent method needed less labour partly due to the lack of uniform pods maturity in blackgram population. Since the pods produced by the early flowers, matures early, harvesting the first pod from each plant without waiting for complete plant maturity would be a very practical way of conducting the SSD method. By contrast, the BM and SPP required complete maturity of a plant. Hence, this is another advantage that favour SSD in the application of blackgram breeding. Byron and Orf (1991) reported single seed descent with early maturity (SSDE) selection procedure in soybean lines. Similarly, SSD in blackgram may produce some early maturing recombinant (transgressive segregants) where other methods may not. Many other researchers like Boerma and Cooper (1975b) in soybeans; Rao (1980) in linseed; Rahman and Bahl (1985); Berin (1981) in gram and Pawar *et al.* (1985) in two wheat crosses, reported similar results.

Comparison of Bulk Method and SSD revealed that these two methods were equally effective in successive generations of different hybrids by showing similar means and genetic variances. Between the two methods SSD is less influenced by sampling problem and natural selection that operate in case of random bulk (Roy, 1976). The results obtained in the present study showed similar behaviour over the two locations. In the present study it was observed that all the three breeding methods were highly influenced by cross combination and environment. Bisen *et al.*, 1988 and Branch *et al.*, 1991 also reported similar results in chickpea and peanut respectively.

Single Plant Progenies maintained high genetic variation and more transgressive segregants for almost all the parameters in the F_4 segregating populations over the two locations and it was followed by SSD breeding methods except in hybrid (9020/9012) as shown in Fig. 5.2c. Three crosses i.e. 9020/Mash 1, Mash 1/9020 and 9020/9012 were outstandingly better in BM especially at NARC (Fig. 5.2a). In most of the crosses BM showed a reduced frequency in most of the crosses for almost all the characters except 100 seed weight at FJ, (Fig. 5.3f) where it showed significant progress even then it ranks third in position. This is similar to the finding of Haddad and Muehlbauer (1981) in lentil and Tee & Qualset (1975) in wheat. Three hybrids that produced better results involve the parents 9020, Mash 1 and 9012. It is worth to mention that these parents possess all the three economic traits i.e., earliness (9012); yield potential (Mash 1) and high seed weight (9020), therefore, breeding of blackgram can be practiced with minimum labour and time involving suitable parental lines.

While comparing all the three methods in the present study it was observed that SPP showed its worth especially at FJ (Fig. 5.2c) where as SSD was better at NARC in all the crosses. Moreover, the results obtained through BM revealed that only three crosses (9020/Mash 1; Mash 1/9020 and 9020/9012) produced better results that were in response to selection at both the locations (Fig. 5.2a). Results in the present study favoured SPP breeding method for most of the characters except number of pod, 5 pods length and seeds pod $^{-5}$ and this was followed by SSD (Figs. 5.3a to 5.3i). However, for 100 seed weight, BM exhibited its worth in some particular hybrids, especially under better management conditions. According to Haddad and Muehlbauer (1981), when progress for characters identification in seed or seedlings is the goal, the SSD method could possibly be improved by some selection on a single seed or single plant basis during advancing generations provided the characters under selection have moderately high heritability.

Similarly, Martin *et al.* (1978) pointed out the same problem in SSD population and showed 55% losses of the original population in a green house study in soybean. Muehlbauer *et al.*, 1981 reported 70% seedling lost due to applying SSD after four generations advancement in lentil. Rahman and Bahl (1985) took one pod instead of one or two seeds from each F_2 population in six crosses of chickpea to minimize this error. Similarly, in the present study two seeds were collected from every plants of F_2 population to F_4 generation to get more applicable results. A linear relationship between SPP and SSD for each generation indicated that two seeds taken from every plant might have reduced loss in recombinants in the proceeding generations. The results of Dahiya and Singh (1985 and 1986) were not in conferring with our findings where they reported that selection after two cycles of selective intermating was found to be the best method for generating productive progeny in mungbean. Vencovsky and Crossa (2003) suggested some measurements of representativeness such as the effective population size (N_e) useful in genetic resources conservation and plant breeding research. They further pointed out that while comparing effective population sizes for the single seed descent (SSD) method versus the bulk system, results showed that SSD maintains genetic drift at a low level and offers a much better protection against random loss of alleles during selfing generations.

Although Gill *et al.* (1995) pointed out that honeycomb method exhibited superiority over Pedigree Selection (PS), SSD and BM for yield per plant and its component traits in mungbean and also pointed out that honeycomb and SSD methods were found suitable for deriving superior lines for seed yield and pods per plant in mungbean. However, SSD method may be preferred for the time required and the cost effectiveness in handling segregating generations of mungbean. Their conclusion was that the pedigree selection, single seed descent and bulk methods were equally effective in deriving the superior lines. This method (honeycomb) might be superior where environmental effects are low as this method reduces the probability of sampling or it might be suitable for some traits in a particular crop. We observed that the breeding methods gave different performance for various hybrids or traits. Bulk method showed better index score at both the locations for three crosses (9020/Mash 1, Mash 1/9020 and 9020/9012) while the same crosses behaved different when we apply SSD and SPP breeding method at both the locations (Figs. 5.2a, b & c).

The traits under study should be highly heritable and predominantly controlled by additive gene effects for exploitation that can be improved through BM, whereas, in case of undesirable linkage, suitable breeding method is very important. Single Seed Descent method is free from the limitations of bulk and pedigree methods. Moreover, it is economical in time, space and energy (Boerma and Cooper, 1975b; Haddad and Muehlbaur, 1981 and Fahim *et al.*, 1998). Under these situations, the SSD method is more suitable than SPP or BM. While concluding other than honeycomb, the SSD method may be preferred for time required and the cost effectiveness in handling segregating generations. As blackgram belongs to *Vigna* species, SSD method may also be applied in early generations segregating populations in deriving improved high yielding lines. It was observed that there has to be a point of coincidence to agree for a particular hybrid or character or both and also for location. Therefore, preference was pointed out for some specific objective to be achieved as described above. Joshi and Witcombe (2002) compared two participatory approaches i.e. farmer managed participatory research (FAMPAR), and informal research and development (IR & D) and reported that benefits from both approaches were considerable, but with certain limitations.

Therefore, a selection scheme was laid down or formulate for all the three breeding methods which would be preferred or may be fit for one or more, out of nine characters at both the locations (Table 5.1.1). First preferred group of breeding method revealed that the results obtained from the present study indicated that the plant height, number of branches, 100 seed weight, biological yield and grain yield were effectively improved by applying single plant progenies breeding method in early generation at Fateh Jang (FJ). However, number of branches and harvest index can also be improved by adopting the same breeding method even at NARC location. Dahiya *et al.* (1984) in greengram; Bisen *et al.* (1988) in chickpea and Obisesan (1992) also conducted studies to test the effectiveness of different breeding procedures at more than one locations.

The present study suggested that number of pods, pod length and number of seed per pod can be improved by single seed descent breeding method at NARC, Islamabad location. Dahiya and Singh (1986) also suggested that though some excellent progenies were selected through SSD, it is not as efficient as Selective Intermating and Mass Selection, because it yielded only a small number of productive families. However, they concluded that SSD is economical and the most rapid method of generation advancement. Single Seed Descent selection has also been reported to be comparable to, or even better than, such traditional methods as pedigree, bulk, and /or early generation yield testing, for the development of superior pure lines / recombinant in many crops (Byron and Orf, 1991, Molari *et al.*, 1987 in soybean; Bisen *et al.*, 1988 in chickpea; Singh *et al.*, 1990 in mungbean; Branch *et al.*, 1991 in peanut; Fahim *et al.*, 1998 in rice; Mehta and Zaveri (1998) in *Vigna unguiculata*; and Vencovsky and Crossa, (2003) reviewed as effective population size.

Cooper (1990) suggested that early generation testing is effective in identifying superior pure lines, but requires extra yield testing. The results presented in the present study confirmed these finding of early generation yield testing in blackgram. However, Salmon *et al.* (1978) presented the results on triticale and indicated that pedigree selection and early generation yield testing procedures are equally efficient methods for yield selection. Moreover, Leudders *et al.* (1973) comparing early generation yield testing, bulk, and pedigree selection methods, found no significant differences in mean yield of lines in the F_6 and F_7 which had been selected by any of these methods in the F_4 and F_5. However, they found that early generation yield testing and bulk selection methods in soybeans retained more high yielding lines than did pedigree selection.

Table 5.1.1: Selection scheme of characters preferred by three breeding methods in F_4 generation at two locations.

Preferred Group	**Breeding Method**	**Characters preferred by breeding method**								
1st Preferred Group	SPP-NARC	PH	**Br**				100SW			**HI**
	SPP-FJ	**PH**	**Br**	Pods	5PL	5PS	**100SW**	**BY**	**GY**	
	SSD-NARC		Br	**Pods**	**5PL**	**5PS**		BY	GY	
	SSD-FJ									HI
	BM-NARC									
	BM-FJ									
2nd Preferred Group	SPP-NARC			**Pods**		**5PS**		**BY**	**GY**	
	SPP-FJ									
	SSD-NARC	**PH**					**100SW**			**HI**
	SSD-FJ	**PH**	Br	Pods	5PL	5PS	**100SW**	**BY**	**GY**	HI
	BM-NARC	PH	**Br**		**5PL**			BY	GY	
	BM-FJ	PH				5PS		BY		HI

Bold: Characters preferred first by a breeding method.

Normal: Characters preferred secondly by a breeding method.

In the present study none of the parameter showed its worth across the traits when the bulk method was applied. Khalifa and Qualset (1975) found that short statured segregates were lost if populations of high yielding semidwarfs and low yielding, tall statured cultivars were grown for several generations as bulk. Consequently, they concluded that bulk should not be used for fear of losing desirable semidwarfs. In blackgram, the short statured cultivars were supposed to be preferred because of high yield potential, synchronous maturity and short duration that can be fitted well in various cropping system (Ghafoor *et al.*, 2003).

Single Seed Descent was highly effective for improving plant height, 100 seed weight, biological yield, grain yield and harvest index at FJ location. Plant height and 100 seed weight revealed positive response for their improvement in this breeding method at both the locations. Bisen *et al.*, 1988 compared SSD, yield bulk and seed size bulk in chickpea and reported that variability in seed yield can be exploited through variation in seed size, by selection of the segregating material under different environments and locations. Singh *et al.* 1990 reported different results in mungbean for these traits and suggested improvement through selection. However, Byron and Orf (1991) indicated that no consistent differences were apparent among the selection procedure, i.e. Pedigree, SSD, and SSD with early maturity for maturity, height, lodging, seed weight, or length for two periods. They recommended SSDE procedure as it is most cost effective procedure.

However, the bulk method showed its effectiveness in secondly preferred group of breeding method. Through this method all the traits showed positive response for their improvement except number of pods and 100 seed weight. Bisen *et al.* (1984) also reported that seed size bulk procedure proved to be consistent ones in varying environments as compared to yield bulk and SSD. However, Pawar *et al.* (1985) suggested that the generation mean analysis, on a whole, indicated the preponderance of additive gene effects for almost all the characters and found that SSD method was better than bulk population breeding.

According to Vencovsky and Crossa (2003), while comparing the effective population size for the SSD method versus the bulk system, the SSD maintained genetic drift at a lower level due to gametic control. The SSD method offers a good protection against random loss of alleles during selfing of generations, especially under small sample size. In the present study, as already mentioned that at FJ, the experiment were conducted to farmer's condition using a sort of participatory approach to compare validity of various breeding methods. According to Fahim *et al.* (1998) single seed descent is at least as effective as the other methods, because it is less costly, more effective and rapid. Therefore, in SSD it is possible to predict the potential of a cross on information obtained from the early generations of the pedigree. Single seed descent was the method least influenced by natural selection; therefore, it may be useful method in greenhouse or winter nursery environment where the genotype may perform differently than under field conditions. The results obtained in the present study showed that SSD method's performance was much better than BM in all the crosses at both the location except three crosses (9020/Mash 1, Mash 1/9020 and 9020/9012), while on the other hand its mean performance was low as compared to SPP method (Fig. 5.2b). However, due to the merits of SSD, we also preferred to recommend this method for blackgram improvement. Therefore, the result mentioned above showed similarity with the finding of our studies. But Singh *et al.* (1998) reported that the influence of the type of cross and the selection scheme on the mean grain yield and other traits of the progenies were minimal in wheat crosses. However, the finding of our study on blackgram differed with their studies conducted in wheat.

Superior progenies for each character were always maximum in the group of progenies derived from the application of selection pressure i.e., in SPP breeding method for that particular character (Fig. 5.2c). The results observed in the present study in SPP breeding method through single plant selection for grain yield were also similar to those previously reported by Patil *et al.* (1994) in safflower where higher mean grain yield was observed in F_3 and F_4, indicating the effectiveness of single plant selection. Similar results have been reported by Salimath and Bahl (1985a) in chickpea. In SPP breeding method the mean performance of all the characters per plant was higher than the other breeding methods. Hence these results suggested that selection based on individual plant selection on yield basis is more effective than selection based on the other traits.

Allard (1960) reported that pedigree and bulk methods of selection are classic, in textbook method. Both methods have their advantages and disadvantages in term of genetic gains and cost efficiency. Singh *et al.* (1998) reported that selected bulk appears to be the most attractive selection scheme in terms of genetic gains and cost efficiency in wheat. But in the present study SPP and SSD appeared to be the best methods for genetic gains and cost effectiveness. The reason may be that in bulk method a large population size and interplant competition may be misleading in selection of superior plant in F_3 and in later generations. However, in SSD breeding method, the population size is in certain limits and in SPP, due to the pooling of better performing genes leading towards higher generations is time consuming, record maintaining and costly method of crop improvement. Singh *et al.* (1998) also reported that BM procedure of generation advancement in the F_2 was unable to identify plants with increased yield in F_3 and yield *per se* could not be used as a reliable criterion for rejection/selection of crosses in the F_3. So, SSD is the only suitable breeding method for blackgram improvement after SPP. Hence, the results obtained in present study are partially in agreement with the previous finding of authors mentioned above.

Plant height plays an important role in grain yield improvement in blackgram (Singh *et al.*, 1994 and Nagarajan and Rangasamy, 1997). Intermediate plant height transgressive segregants were desirable for better grain yield. The results obtained in the present study revealed that maximum transgressive segregants were observed in SPP at both the locations and it was followed by SSD at both the locations where similar results were obtained. Kant and Singh (1998) reported similar high transgressive segregation for plant height in lentil crosses. Taller plants or plant of extra height will lodge and spoil the quality and quantity of grain yield and it also causes a delayed maturity (Haddad and Muehlbauer, 1981). The results obtained in present study in blackgram are also similar as previously described by Liu *et al.* (1984) and Ali and Tufail (1991) in mungbean.

Results of present study revealed that maximum number of plant were around the mid parent in SPP and it was followed by SSD breeding method. Only one or two crosses deviated from these results. Bulk method produced negative transgressive segregation almost in all the cases allowing progenies of short plant stature which become ultimately enhance the possibility of short plant type in future generations. As many researchers are convinced that SSD breeding procedure has also been reported to be comparable to, or even better than, such traditional methods as pedigree, bulk and/or early generation yield testing, for the development of superior pure lines of soybean, wheat, Bengal gram, pigeonpea and lentil. However, Dahiya *et al.*, 1987 reported superiority of SSD over single plant selection (SPS) in mungbean which is contrary to our findings. But, Pawar *et al.*, 1985 reported similar results in wheat as were achieved in the present study.

As blackgram and greengram are much closer to each other and belong to the same genus so the criteria of selection for high yielding genotypes on pod per plant basis could also be recommended (Atkins, 1964 and Ali and Tufail, 1991). The correlation results in the present study also revealed positive association of number of pods per plant with grain yield in all the crosses (Table 4.1.12). Similar results were already reported by Kumandi and George (1982); Gowda (1984); Murthy (1984) in cowpea; Khan (1985) in mungbean; Kant and Singh (1998) in lentil; Mehta and Zaveri (1998) in *Vigna unguiculata*; Sajikumar *et al.* (1998) also pointed that harvest index coupled with pods/plant and primary branches were reliable selection criterion in segregating generations to increase yield in blackgram. Present study suggested that this character can more effectively be exploited by applying SSD breeding method as it is more cost effective, less time consuming and also less laborious. However, Prasad and Ram (1985) suggested that bulk population breeding would be more effective method in breeding for more number of pods/plant in the populations of chickpea crosses. Moreover, they also recommended SSD method as it is least influenced by natural selection in French bean. Davis and Evans (1977) reported increased efficiency of selection by including information on plant type traits. It was further suggested that experiments on selection for pods/plant in French bean involving F_3, F_4 etc. may be pursued. While in the present study we also investigated these parameters in F_3 and F_4 generations.

Pods length and seed pods^{-5} revealed similar pattern for all the three breeding methods, therefore, it is important to investigate genetic pattern of grain yield and its related traits. According to present study these traits can be improved preferably by applying SSD at research station whereas, SPP at FJ. Shamsuzzaman *et al.* (1983); Obisesan (1985); Sigh and Singh (1997) in wheat and Mehta and Zaveri (1998) in cowpea reported similar results for these traits. Sajikumar *et al.* (1998) also reported positive correlation between yield and seed per pod in blackgram. Moreover, Liu *et al.* (1984) reported that moderate seeds per pods would be preferred in mungbean. They reported that the lack of strong correlation between seeds per pod and yield might be due to the production of higher number of seeds per pod at the expense of their seed weight.

Grain yield is the final harvest that is directly related to material production and frequency pattern. In the present study, keeping in view the importance of this valuable trait, emphasis was given to identify the best hybrid for exploiting seed weight as bold seeded blackgram are liked by the consumers. Consequently, bold seeded cultivars are low yielding. Therefore, SPP produced bold seeded hybrids; Mash 3/Mash 1, Mash

3/9026, Mash 1/9026, 9020/Mash 3, 9020/Mash 1 and Mash 1/9020, especially at FJ, where the superior plants could express their full potential of seed weight. The hybrid 9020/Mash 1 was observed better and this genetic variance could be utilized by all the methods. As it is universally known that the yield is a complex character influenced by several factors, it is possible to get varying estimates of h^2 for seed yield of the same population over generations and also found that realized h^2 estimates from different crosses and breeding procedures were quite in consistent (Bisen *et al.*, 1985).

In another study (Bisen *et al.*, 1984) reported that seed size bulk procedure proved to be consistent one in varying environments as compared to yield bulk and single seed descent. It has long been emphasized that single plant selection, the basis of grain yield in early segregating population is ineffective as a means of developing high yielding pure lines in self-pollinated crops. The mean performance of SPP in all the eleven crosses at FJ showed better results except 9020/9012 and it was followed by SSD at NARC (Fig 5.2b & c). However, the results obtained through SPP and SSD for grain yield at NARC and FJ, respectively were at par (Fig. 5.3h). Early generation selection in F_3 generation has been advocated by Shebeski and Evans (1973) for grain yield in wheat. McNeal *et al.* (1978) also reported that the selection in F_3 generation for five yield components was effective. Knott (1979) reported that F_3 selection based on a two replicate yield test showed a small increase (1.5%-3.8%) in yield over the single seed descent procedure but the extra work involved was not justified. Knott and Kumar (1975), Tee and Qualset (1975), Wright and Thomas (1978) and Knott (1979) have also suggested use of SSD procedure as an alternative to pedigree and bulk methods of selection. It was found by these workers that the procedure was often superior or was at least equally efficient to the pedigree and bulk methods.

However, Sneep (1977) found that SSD procedure would result into the loss of many genotypes through genetic drift. Mass selection was found to be superior to pedigree selection and selection for yield *per se* (Dahiya *et al.*, 1984). In another study they pointed out that an early generation yielding testing selection procedure is more efficient than visual selection for yield improvement in green gram. Kant and Singh (1998) reported three indigenous crosses in lentil were promising because in addition to yield per plant, transgressiveness for yield components was also observed in F_2 and F_3 generation. Sajikumar *et al.* (1998) also observed similar result for grain yield and its components in blackgram genotypes. Singh *et al.* (1998) reported that harvest index and pods/plant in conjunction with secondary branches were helpful in selection for yield. He also indicated that BM and yield *per se* could not be used as a reliable criterion for rejection/selection of crosses in F_3 generation.

Bhatt and Derera (1973) recommended a limited visual selection system in which single plant selection from F_2 to F_4 is carried out for most of the simply inherited characters, and when the progenies appear to be reasonably homozygous for these characters, lines derived from $F_2 - F_4$ are bulked and carried forward as strains for yield trials. The resulting cultivars are relatively heterogeneous and may have an advantage in unstable environments. Tee and Qualset (1975) reported genetic variation within each generation to be greater for SSD than for Bulk Population for heading time and grain yield for one hybrid and reverse for other for height and yield. Fahim *et al.* (1998) reported that SSD is at least as effective as the other methods, is less costly, and rapid and three generations can be raised per annum in rice. Mehta and Zaveri (1998) reported the superiority of SSD over pedigree selection and mass selection schemes for the production of high yielding progenies, maintaining high variability and for handling the segregating materials.

Harvest index reported in the present study revealed that 35% and above is helpful in selection of better as been reported by Ghafoor *et al.*, 2001. The comparison of three methods showed the accumulated results of F_4 generation for this character. The comparison indicated that SPP breeding method will be helpful for high harvest index plant progenies at NARC. The results of remaining two breeding methods at NARC showed more plants of high harvest index (Fig. 5.3i). However, FJ location did not favour the high harvest index values as compared to NARC (Fig. 5.3i). Desired plant progenies could be picked up through SPP breeding methods at NARC locations could be recommended. Although harvest index is greatly influenced by environmental factor but as the homozygosity level of the parents was very high therefore, stability for this character is expected. According to Fischer and Kertesz (1976) the harvest index, which may be successful as a selection criterion for yield potential in similar plant types with equal productivity, fails when different plant types of varying productivity are present in one F_2 population (Okolo, 1977). However, in the latter case it is important to consider productivity first and foremost, because it is the foundation upon which grain yield is built. Patel and Shah (1982) and Ghafoor *et al.* (1993) observed high selection indices in blackgram germplasm where harvest index ranged from 26 to 36%.

Grafius (1965) and Brim (1966) suggested that single seed descent (SSD) selection method is widely used in self pollinated crops and offers several advantages, one being the high level of genetic variability that can be maintained among the lines of the population after successive generations of selfing. In other words, the SSD produces a better representation of the original population in advanced generations of selfing. While concluding the discussion it is clear that the results obtained at both the locations from the present study presented in Fig. 5.1 in present revealed that SPP showed high index score at FJ and it was followed by SSD at NARC. However, SPP also revealed high index score (114) at NARC which is insignificantly differed from index score (140) of SSD at NARC, location.

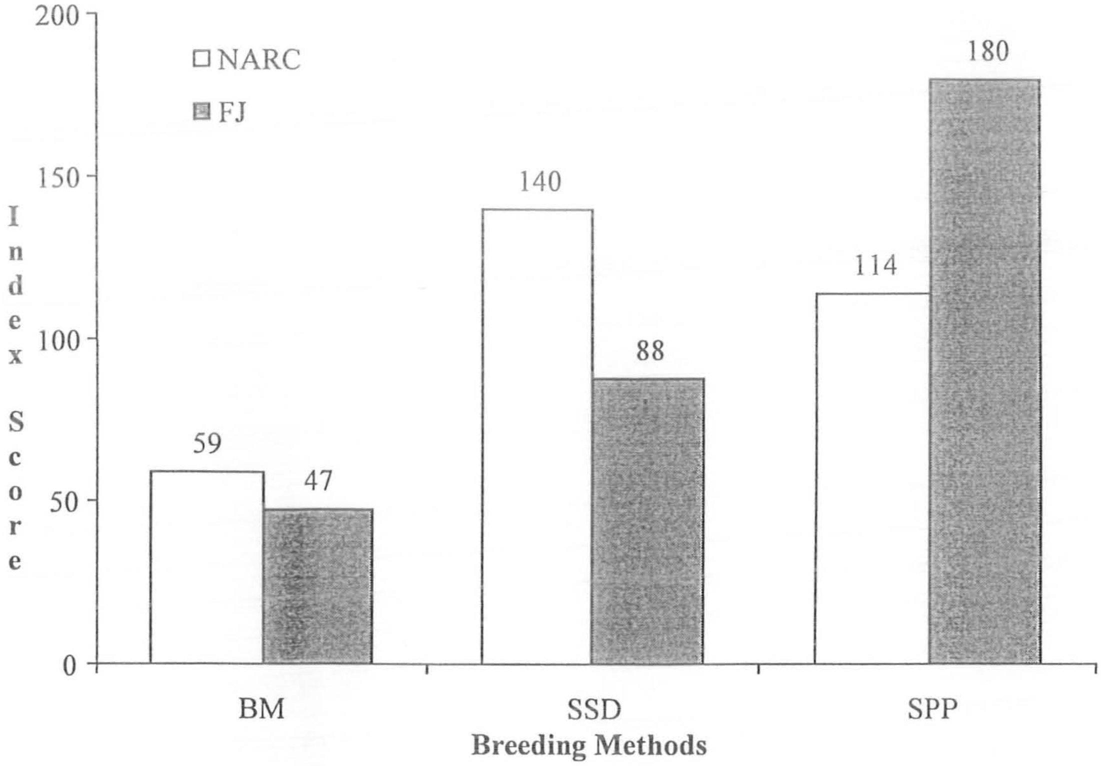

Fig. 5.1: Graphic presentation of Bulk Method, Single Seed Descent and Single Plant Progeny method by allotting index score at 2 locations.

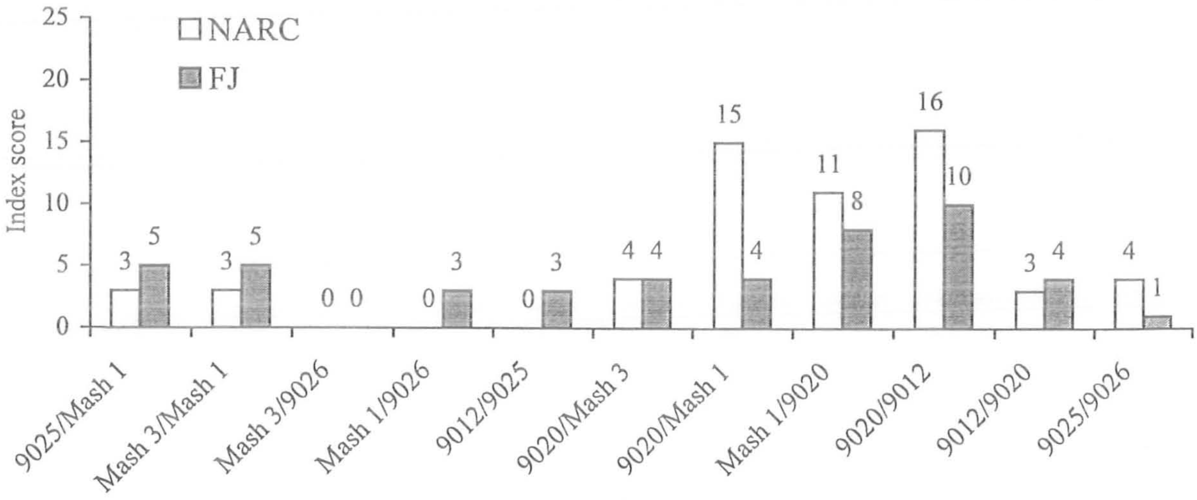

Fig. 5.2a

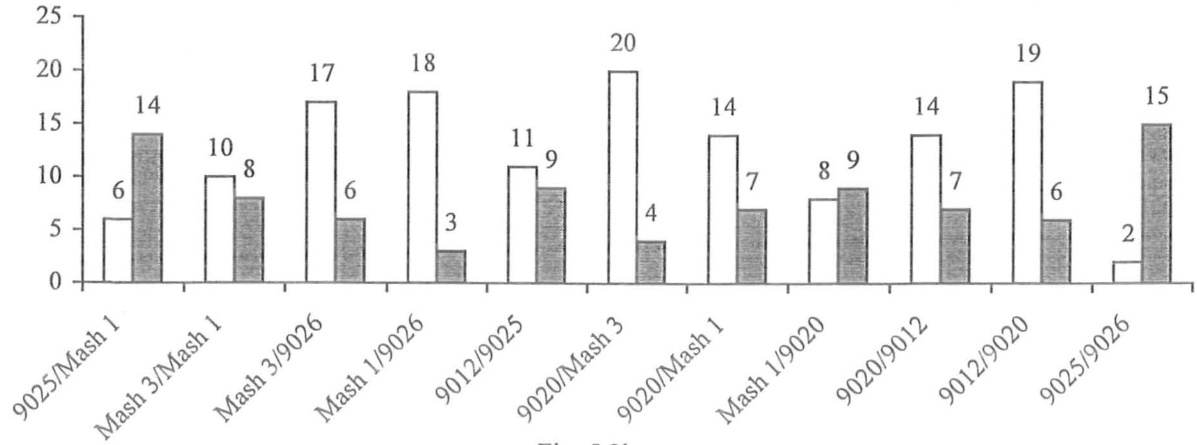

Fig. 5.2b

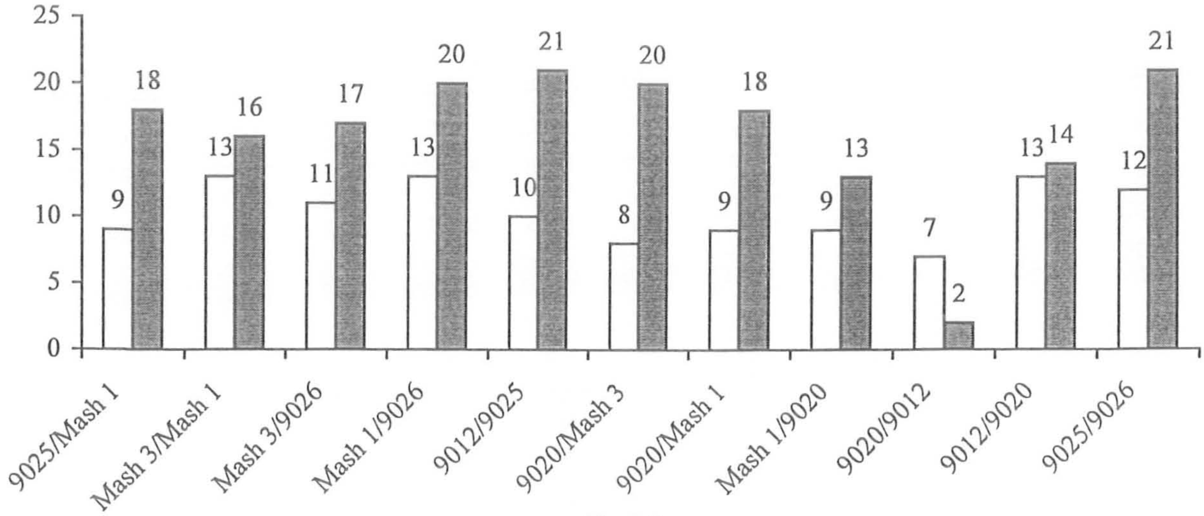

Fig.5.2c

Figs. 5.2: Index score presentation in bulk method (a), single seed descent (b), single plant progenies (c) breeding method in 11 crosses at 2 location

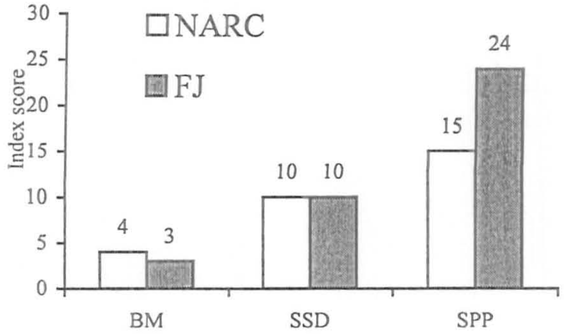

Fig. 5.3a: Plant height

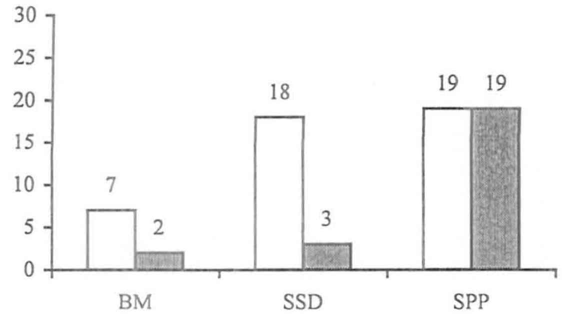

Fig. 5.3b: Branches

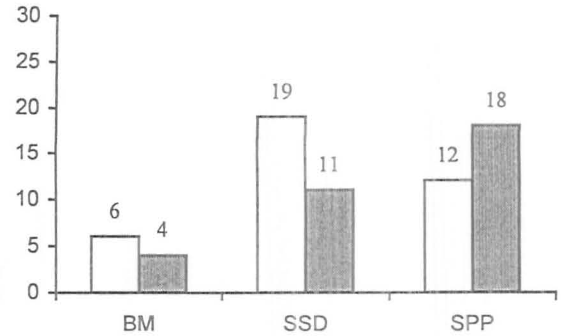

Fig. 5.3c: Pod

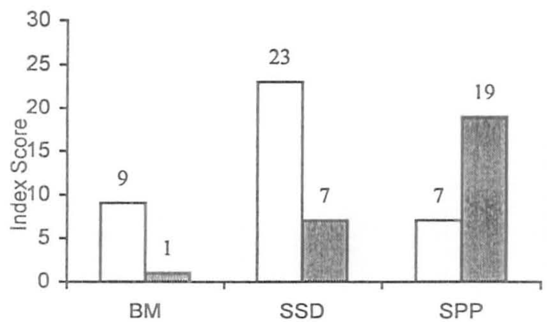

Fig. 5.3d: Pods length

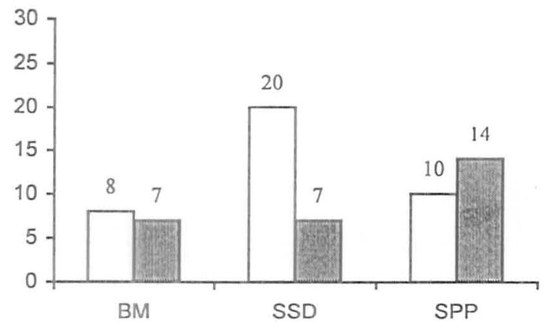

Fig. 5.3e: Pod seed

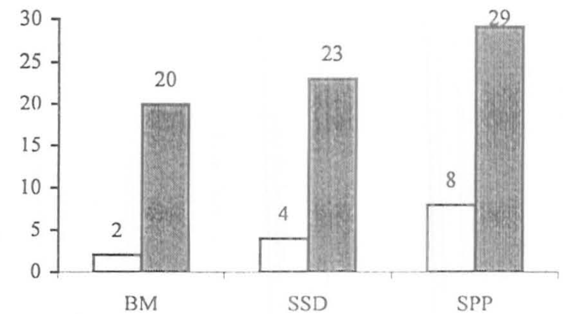

Fig. 5.3f: 100 seed weight

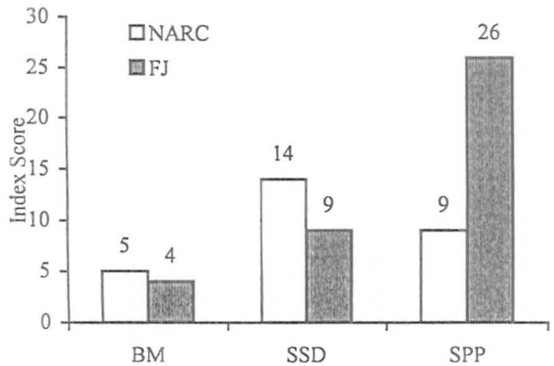

Fig. 5.3g: Biological yield

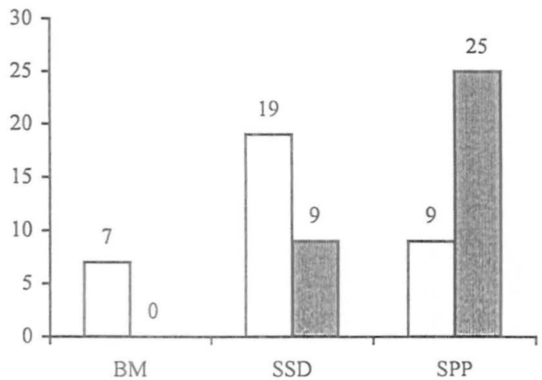

Fig. 5.3h: Grain yield

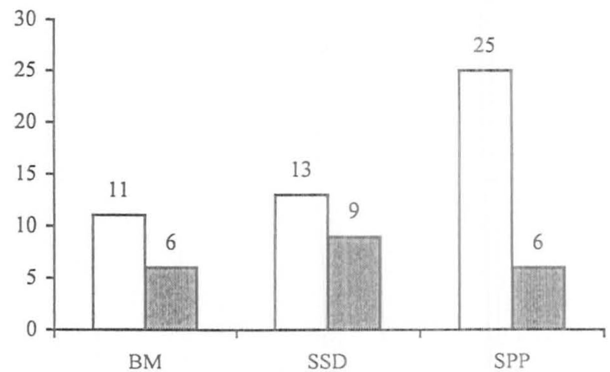

Fig. 5.3i: Harvest index

Fig. 5.3a-i: Graphic presentation of 3 breeding methods based on index score for 9 traits at NARC and FJ

5.2 Inheritance of Qualitative Traits

Monogenic markers are useful in estimating the rate of crossing in predominantly self pollinated crops like blackgram (Senapati and Roy (1990). They also help in identification of F_1 hybrids in the breeding programme. Heterozygous are not possible to detect in case of complete dominance for morphological markers. Sen and Jana (1963) and Ghafoor *et al.* (2003) reported inheritance of pod colour and found black colour dominant over brown colour in blackgram.

Joint segregation of character pairs revealed normal distribution of independent assortment (9:3:3:1) for most of the character pairs but some distorted segregation were also observed that indicated linkage for these characters pair. The character pairs *HH* vs *BB*, *HH* vs *CC*, and *HH* vs *SS*, segregated in a normal independent assortment while the remaining pairs i.e. *BB* vs *SS, BB* vs *CC* and *CC* vs *SS* were linked in all cases. Deviation from normal assortment might be due to linkage for some alleles, and this type of distorted ratios have been observed by Kazan *et al.* (1993) in chickpea; Zamir and Tadmor (1984); Muehlbauer *et al.* (1989) in lentil; Weeden and Marx (1987) in pea; Koenig and Gepts (1989) in *Phaseolus* and Ghafoor *et al.* (2003) in blackgram.

As linkage between black pod colour and presence of spots on seed coat in two different hybrids may be due to genes for these two characters from same origin. Ghafoor (2000) observed similar result between these two traits in blackgram. Morphological markers are limited in plants especially, blackgram because limited genetic work has been conducted on this crop. Five morphological loci have been reported by Kazan *et al.*, 1993 in chickpea. The identified linkage in the present study is suggested to be used for initial mapping of genome as there is no information of this type in blackgram. The arrangements proposed were based on linkage observed between genetically diverse cultivated blackgram in the present study. The usefulness of the mapped marker loci should be realized when loci affecting QTLs including diseases and other economically important genes are added to the linkage group. The use of closely linked markers should facilitate breeding by giving a unique identity by tagging the genes of economic importance and by providing a mean of selection in the absence of nurseries and screening procedures that can be costly and time consuming. It is suggested to utilize diverse parents for both qualitative and quantitative traits for planning experiments for inheritance and mapping. Further, enhancement of markers (morphological, protein and DNA) is suggested to have a precise understanding of linkage groups in blackgram.

5.3 Heterosis Study

Heterosis study was based on 11 hybrids over four generations at NARC, Islamabad. In most of the cases high mean performance failed to express high heterotic effects that in turn did not valued for the production of transgressive segregation, therefore individual crosses are required to investigate for selection purpose. Varying degrees of hybrid vigour have been reported by various researchers in chickpea (Bakhsh *et al.*, 2001), blackgram (Ghafoor *et al.*, 2000) and mungbean (Aher and Dahat, 1999). In the present study transgressive segregates were observed in the later generations of hybrids, i.e., Mash 3/Mash 1, 9012/ 9025 and 9020/Mash 1 for most of the traits. Recombination occasionally leads to the production of desirable features not found in either parent, however the best chance of success lies in selection of suitable parents (Allard 1966). Estimates of the form of genetic variation are fundamental to the identification of suitable breeding strategies that is influenced by various factors (Bailey *et al.*, 1980) Presence of additive genes in the identified hybrids suggests that hybrids may provide a desirable alternative to the development of pure lines (Kunta *et al.,* 1997 and Ghafoor *et al.*, 2000). The yield or adaptation of the parents is not necessarily a good indicator of superior recombination although it is a complex phenomenon that is affected by a number of factors. One common parents involved in different hybrids performed inconsistently that may not necessarily due to common additive genes although hybrid vigour and transgressive segregation are affected by a number of factors (Guillen-Portal *et al.*, 2003). This is because hybrid performance often depends on complex interactions among genes and tracking back of a particular combination is even not possible involving same parents, researchers and locations.

Selection is a real art of a researcher although nature of gene-action and basic knowledge about parents help in predicting hybrid performance. For improvement of seed yield in blackgram, breeding methods, including biparental mating among selected F_2 segregants from crosses involving the parents 9020 and Mash 1, need special consideration. Malhotra *et al.* (1979) suggested that from further segregating generations of biparental populations, desirable plants can be selected and used as in other conventional breeding programme. Simultaneously, the hybrids involving the parents 9020 and Mash 1 may be exploited through modified diallel selective mating system (Frey 1975 and Ghafoor 2001). By this technique, improvement in the population can effectively be made and at the same time superior segregants are provided for further improvement in blackgram.

Since the end products of a breeding programme of a strongly self pollinated crop are usually pure-lines, there is usually little scope for exploiting non-additive genetic variation (Chauhan & Singh 1997), hence selection in appropriate early generation is to be investigated for particular hybrid for specific character that will ultimately save the time and labour involved for breeding blackgram. The magnitude of hybrid vigour in the present study was more influenced by the average performance of parents combined with genetic diversity. Grouping of hybrids by multivariate methods is of practical value to breeders of blackgram although this technique has been implied to study genetic dissimilarities among pure-lines but it gave important information in breeding material that helped in assessment of genetic diversity that could be predicted for future development.

The F_3 and F_4 generations in the same vicinity based on more that three fourth variability for 9 characters explained the similarity for these two generations, hence either generation of selected hybrids could be exploited for selection superior plant progenies. Selected hybrids from diverse groups could be used for further breeding using selective diallel mating. Various hybrids identified on the basis of genetic diversity and better performance in the F_1 could be used for transfer of the desirable genes (Clements & Cowling 1994).

These findings show that variability in parents is also related to the variation of particular cluster involving those parents. The hybrids involving better genotypes from distinct clusters are likely to produce better transgressive segregates that are needed to pick up for breeding blackgram. Visual inspection of individual plants and unreplicated progenies of selected plants might be used as the basis of selection in segregating generations (Dahiya *et al.*, 1983). Zubair *et al.* (1989) in *Vigna radiata* and Ghafoor *et al.* (1990) in *Vigna mungo* also suggested simple selection followed by carefully in large segregating population to find out the transgressive segregants for effective improvement in these two crops. On the other hand, selection for yielding ability and other characters influenced by the environment is generally postponed until later generations using SSD to avoid losing desirable recombinants.

CONCLUSIONS

CONCLUSION

- Overall, SSD was observed the best at research center, whereas, at farmer's field SPP was the best for most of the hybrids and characters. Although, SSD was insignificant at both the locations. This indicated that breeding program at farmer's field reduced the chances of selection in SSD method that is expected due to high loss in genetic variation due to poor management practices.

- On the basis of these results, Single Seed Descent would be suggested due to its cost effectiveness, less labour and time required for blackgram improvement under a range of management practices.

- Three crosses (9020/Mash 1, Mash 1/9020 and 9020/9012) showed its performance to Bulk Method at both the locations that indicated specificity for hybrids or characters.

- Three crosses (Mash 3/Mash 1, 9012/9025 and 9020/Mash 1) showed better performance over all the four generations. Hence, crosses could be exploited through simple selection from F_4 to improve yield potential.

- All the four qualitative characters revealed monogenic inheritance (3:1) ratio along with some linkage that cloud be used for initial mapping.

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APPENDICES

APPENDIX-I

Index score by pooling of methods according to cross wise.

Crosses	Breeding Methods								
	Bulk Method F_4			Single Seed Descent F_4			Single Plant Progeny F_4		
	NARC	FJ	Both Loc	NARC	FJ	Both Loc	NARC	FJ	Both Loc
9025/Mash 1	3	5	**8**	6	14	**20**	9	18	27
Mash 3/Mash 1	3	5	**8**	10	8	**18**	13	16	29
Mash 3/9026	0	0	**0**	17	6	**23**	11	17	28
Mash 1/9026	0	3	**3**	18	3	**21**	13	20	33
9012/9025	0	3	**3**	11	9	**20**	10	21	31
9020/Mash 3	4	4	**8**	20	4	**24**	8	20	28
9020/Mash 1	15	4	**19**	14	7	**21**	9	18	27
Mash 1/9020	11	8	**19**	8	9	**17**	9	13	22
9020/9012	16	10	**26**	14	7	**21**	7	2	9
9012/9020	3	4	7	19	6	**25**	13	14	27
9025/9026	4	1	**5**	2	15	**17**	12	21	33

APPENDIX-II

Index score by pooling of methods according to traits wise.

Traits	Breeding Methods								
	Bulk Method F_4			Single Seed Descent F_4			Single Plant Progeny F_4		
	NARC	FJ	Both Loc	NARC	FJ	Both Loc	NARC	FJ	Both Loc
Plant height plant^{-1}	4	3	7	10	10	**20**	15	24	**39**
No. of branches plant^{-1}	7	2	**9**	18	3	**21**	19	19	**38**
No. of pod plant^{-1}	6	4	**10**	19	11	**30**	12	18	**30**
5 Pods length	9	1	**10**	23	7	**30**	7	19	**26**
5 Pods seed	8	7	**15**	20	7	**27**	10	14	**24**
100 seed weight plant^{-1}	2	20	**22**	4	23	**27**	8	29	**37**
Biological yield plant^{-1}	5	4	9	14	9	**23**	9	26	35
Grain yield plant^{-1}	7	0	7	19	9	**28**	9	25	**34**
Harvest index	11	6	**17**	13	9	**22**	25	6	**31**
Total	**59**	**47**	**106**	**140**	**88**	**228**	**114**	**180**	**294**